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(21) Application No.	Patent application no. H9-343740	(71) Applicant	000004112 Nikon Corp. 3-2-3 Marunouchi, Chiyoda-ku, Tokyo
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(31) Priority Application No.	Patent application no. H8-332843	(72) Inventor	Kenji Nishi c/o Nikon Corp. 3-2-3 Marunouchi, Chiyoda-ku, Tokyo
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(33) Priority Country	Japan (JP)	(74) Agent	Atsuji Tateishi, patent attorney (and 1 other)

(54) Title of the invention: Projection Exposure Apparatus and Projection Exposure Method

(57) Abstract

Purpose: To improve throughput and achieve miniaturization and weight-reduction of a substrate stage.

Configuration: The operations of two stages are controlled so that during a period in which exposure is performed on a substrate W1 through a projection optical system

PL while the plate spring of a stage WS1 is managed based on the use of measured values obtained by using length-measuring axes BI1X and BI3Y, a positional relationship between an alignment mark on a substrate W2 on a stage WS2 and a fiducial mark plate FM2 can be accurately detected based on a detection result of an alignment system 24b and a measured value obtained by using a length-measuring axis BI5Y. In addition, the operation of the stage WS2 is controlled so that when operations for both stages are completed, an interferometer of the length-measuring axis BI3Y is reset to a state in which the position of the stage WS2 can be measured based on the use of the measured value obtained by using the length-measuring axis BI3Y, and the fiducial mark plate FM2 is positioned at a position at which a positional relationship with a predetermined reference point (a projection center of a mask pattern image) within a projection area of the projection optical system can be detected.

Scope of Patent Claims

Claim 1

An exposure apparatus for exposing sensitive substrates by projecting an image of a pattern formed on a mask via a projection optical system onto the sensitive substrates, the projection exposure apparatus comprising:

a first substrate stage which is movable on a two-dimensional plane while holding a sensitive substrate;

a second substrate stage which is movable independently from the first substrate stage (WS1) on the same plane as that for the first substrate stage while holding a sensitive substrate;

an alignment system provided apart from the projection optical system, for detecting a mark on the substrate stage or a mark on the sensitive substrate held on the substrate stage;

an interferometer system provided with a first length-measuring axis for always measuring a position of the first substrate stage in a direction of a first axis from one side in the direction of the first axis passing through a projection center of the projection optical system and a detection center of the mark detecting system, a second length-measuring axis for always measuring a position of the second substrate stage in the direction of the first axis from the other side in the direction of the first axis, a third length-measuring axis which perpendicularly intersects the first axis at the projection center of the projection optical system, and a fourth length-measuring axis which perpendicularly intersects the first axis at the detection center of the alignment system, the interferometer system measuring two-dimensional positions of

the first and second substrate stages, respectively, by the aid of the length-measuring axes; and

control means for controlling the operations of the two substrate stages so that a position of a first stage of the first substrate stage and the second substrate stage is managed based on the use of a measured value obtained by using the third length-measuring axis of the interferometer system, and during a period in which the sensitive substrate on the first stage is exposed, a positional relationship between an alignment mark on the sensitive substrate held on the second stage of the first substrate stage and the second substrate stage and a reference point on the second stage is detected based on the use of a detection result obtained by using the alignment system and a measured value obtained by using the fourth length-measuring axis of the interferometer system, and then controlling an operation of the second stage so that an interferometer of the third length-measuring axis is reset to a state in which a position of the second stage can be measured based on the use of a measured value obtained by using the third length-measuring axis, and a reference point on the second stage is positioned at a position at which a positional relationship with a predetermined reference point in a projection area of the projection optical system can be detected.

Claim 2

The projection exposure apparatus according to Claim 1, characterized in that:

the apparatus includes another alignment system having a detection center on the first axis, disposed on a side opposite to the alignment system with respect to the projection optical system, wherein the interferometer system is provided with a fifth length-measuring axis which perpendicularly intersects the first axis at the detection center of the other alignment system; and

the control means controls the operations of the two substrate stages so that the position of the first stage is managed based on the use of the measured value obtained by using the third length-measuring axis of the interferometer system, and during the period in which the sensitive substrate on the first stage is exposed, the positional relationship between the alignment mark on the sensitive substrate held on the second stage and the reference point on the second stage is detected based on the use of a detection result obtained by using the alignment system and a measured value obtained by using the fourth length-measuring axis of the interferometer system, and then controls the operation of the first stage so that an interferometer of the fifth length-measuring axis is reset to a state in which the position of the first stage can be measured based on the use of the measured value obtained by using the fifth length-measuring axis, and a reference point on the first stage is positioned at a position within a detection area of the other alignment system.

Claim 3

The projection exposure apparatus according to Claim 2, characterized in that:

the projection exposure apparatus further comprises a transport system for performing delivery of the sensitive substrate between the first substrate stage and the second substrate stage; and

the control means controls the delivery of the substrate between the first stage and the transport system to be performed in a state in which the reference point of the first substrate stage is positioned at a position within the detection area of the other alignment system.

Claim 4

The projection exposure apparatus according to Claim 1, characterized in that:

reference marks as the reference points of the stages are formed on the first substrate stage and the second substrate stage, respectively;

a predetermined reference point within the projection area of the projection optical system is the projection center of the pattern image of the mask; and

the apparatus further comprises mark position detection means for detecting a relative positional relationship between the projection center of the pattern image of the mask and the reference marks on the stages via the mask and the projection optical system.

Claim 5

A projection exposure method for exposing sensitive substrates by projecting an image of a pattern formed on a mask via a projection optical system onto the sensitive substrates, characterized in that the method comprises:

preparing two substrate stages, each of which is movable independently on a same plane while holding a sensitive substrate;

exposing a sensitive substrate held on one of the two stages by projecting the pattern image on the mask onto the sensitive substrate while measuring a position of the first stage by using a predetermined interferometer, and during a period when the substrate held on the first stage is exposed, measuring a positional relationship between an alignment mark on a sensitive substrate held on the other one of the two stages and a reference point on the second stage while measuring a position of the second stage by using another interferometer different from the predetermined interferometer;

after the exposure for the sensitive substrate held on the first stage is completed, resetting the predetermined interferometer to a state in which the position of the second stage can be measured by the predetermined interferometer, and

positioning a reference point of the second stage to a position at which a positional relationship with a predetermined reference point within a projection area of the projection optical system can be detected; and

performing alignment between the sensitive substrate held on the second stage and the pattern image of the mask by using the predetermined interferometer being reset based on the measured positional relationship.

Claim 6

A projection exposure apparatus for exposing sensitive substrates by projecting an image of a pattern formed on a mask via a projection optical system onto the sensitive substrates, characterized in that the apparatus comprises:

a first substrate stage which is movable on a two-dimensional plane while holding a sensitive substrate;

a second substrate stage which is movable independently from the first substrate stage on the same plane as that for the first substrate stage while holding a sensitive substrate;

an alignment system provided apart from the projection optical system, for detecting a reference mark on the substrate stage and a mark on the sensitive substrate held on the substrate stage;

an interferometer system provided with a first length-measuring axis for measuring a position of the first substrate stage in a direction of a first axis from one side in the direction of the first axis passing through a projection center of the projection optical system and a detection center of the mark detecting system, a second length-measuring axis for measuring a position of the second substrate stage in the direction of the first axis from the other side in the direction of the first axis, a third length-measuring axis which perpendicularly intersects the first axis at the

projection center of the projection optical system, and a fourth length-measuring axis which perpendicularly intersects the first axis at the detection center of the alignment system, the interferometer system measuring two-dimensional positions of the first and second substrate stages, by the aid of the length-measuring axes; and

control means for managing a position of one stage of the first substrate stage and the second substrate stage by using the third length-measuring axis of the interferometer system, managing a position of the second stage by using the fourth length-measuring axis during a period in which a sensitive substrate on the first stage is exposed, and calculating a positional relationship between a mark on the sensitive substrate held on the second stage and a reference mark on the second stage by using the alignment system, the control means managing the position of the second stage by using the third length-measuring axis after the exposure for the sensitive substrate held on the first stage is completed, and calculating a positional relationship between a projection position of the pattern image of the mask by the projection optical system and the reference mark on the second stage.

Claim 7

The projection exposure apparatus according to Claim 6, characterized in that after the sensitive substrate held on the first stage is exposed, and when the positional relationship between the projection position of the pattern image of the mask by the projection optical system and the reference mark on the second stage is calculated, the measured value obtained by using the third length-measuring axis of the interferometer system is reset.

Claim 8

The projection exposure apparatus according to Claim 6, characterized in that the control means executes exposure for the sensitive substrate held on the second

stage while controlling the position of the second stage based on the positional relationship between the mark on the sensitive substrate held on the second stage and the reference mark on the second stage and the measurement result obtained by using the third length-measuring axis when the positional relationship between the projection position of the pattern image of the mask by the projection optical system and the reference mark on the second stage is calculated.

Claim 9

The projection exposure apparatus according to Claim 8, characterized in that the control means performs positioning of the second stage so that the reference mark on the second stage falls within the detection area of the alignment system after the sensitive substrate held on the second stage is exposed and then performs exchange of the sensitive substrates.

Claim 10

The projection exposure apparatus according to Claim 9, characterized in that a measured value obtained by using the fourth length-measuring axis of the interferometer system is reset when the reference mark on the second stage is detected by using the alignment system.

Claim 11

A projection exposure apparatus for exposing sensitive substrates by projecting an image of a pattern formed on a mask via a projection optical system onto the sensitive substrates, characterized in that the apparatus comprises:

a first substrate stage which is movable on a two-dimensional plane while holding a sensitive substrate;

a second substrate stage which is movable independently from the first substrate stage on the same plane as that for the first substrate stage while holding a sensitive substrate;

a transport system for delivering the sensitive substrate between the first substrate stage and the second substrate stage;

an alignment system provided apart from the projection optical system, for detecting the reference mark on the substrate stage or a mark on the sensitive substrate held on the substrate stage; and

control means for controlling the two substrate stages so that the second stage performs an exposure operation during a period in which a first stage of the first substrate stage and the second substrate stage performs the delivery of the sensitive substrate with respect to the transport system, wherein the control means controls the first stage so that the reference mark on the first stage falls within a detection area of the alignment system when the first stage performs the delivery of the sensitive substrate with respect to the transport system.

Detailed Description of the Invention

[0001]

Technical Field to which the Invention belongs

The present invention relates to a projection exposure apparatus and a projection exposure method, and more specifically, to a projection exposure apparatus and a projection exposure method for exposing a sensitive substrate by projecting an image of a pattern formed on a mask via a projection optical system onto the sensitive substrate. In particular, the present invention is characterized in that it enables parallel processing of an exposure operation and another operation by independently moving two substrate stages.

[0002]

Prior Art

Hitherto, various exposure apparatuses have been used when semiconductor devices or liquid crystal display devices are manufactured by the photolithography process. At present, a projection exposure apparatus is generally used, in which the pattern image of a photomask or reticle (hereinafter generally referred to as a "reticle") is transferred via a projection optical system onto a substrate (hereinafter appropriately referred to as a "sensitive substrate") such as a wafer or a glass plate in which a photosensitive material such as a photoresist is applied onto its surface. In recent years, as this projection exposure apparatus, a reduction projection exposure apparatus (so-called stepper) based on the so-called step-and-repeat method is mainly used, in which a sensitive substrate is placed on a substrate stage which is movable two-dimensionally, and the sensitive substrate is moved in a stepwise manner (subjected to stepping) by the substrate stage to repeat the operation for successively exposing respective shot areas on the sensitive substrate with the pattern image of the reticle.

[0003]

Recently, a projection exposure apparatus based on the step-and-scan method (scanning exposure apparatus as described, for example, in Japanese Unexamined Patent Application Publication No. 7-176468), which improved block exposure apparatuses such as this stepper, is also used relatively often. This projection exposure apparatus based on the step-and-scan method has the following merits. (1) The first merit is that since a large field can be exposed using a smaller optical system as compared with the stepper, the projection optical system can be manufactured easily, and a high throughput can be expected due to the decrease in the number of

shots resulting from large-field exposure. (2) The second merit is that an averaging effect can be obtained by scanning the reticle and the wafer relative to the projection optical system, and improvement in distortion and depth of focus can be expected. In addition, it is considered that the scanning projection exposure apparatus will be mainly used in place of the stepper, because a large field will be essential as the degree of integration of semiconductor devices increases, with the progress of time, from 16 M (mega) to 64 M for DRAM, and in the future, 256 M and 1 G (giga).

[0004]

Problems to Be Solved by the Invention

This type of projection exposure apparatus is mainly used as a mass-production apparatus for semiconductor devices and the like. Therefore, there is an inevitable demand to improve the processing power, namely throughput, representing the number of wafers that can be exposed by the apparatus within a predetermined period of time.

[0005]

In this context, in the case of the projection exposure apparatus based on the step-and-scan method, the improvement of throughput can be expected since the number of shots to be exposed in the wafer decreases when a large field is exposed as described above. However, since the exposure is performed during constant speed movement based on synchronized scanning of the reticle and the wafer, it is necessary to provide acceleration and deceleration areas before and after the constant speed movement area. As a result, when a shot having a size equal to a shot size of the stepper is exposed, there is a possibility that the throughput is rather decreased as compared with the stepper.

[0006]

The flow of the processes in this type of projection exposure apparatus is generally as follows.

[0007]

(1) First, a wafer load step is performed, in which a wafer is loaded on a wafer table using a wafer loader.

[0008]

(2) Next, a search alignment step is performed, in which the rough position of the wafer is detected by a search alignment mechanism. Specifically, the search alignment step is performed, for example, based on the contour of the wafer, or by detecting a search alignment mark on the wafer.

[0009]

(3) Next, a fine alignment step is performed, in which the accurate position of each of the shot areas on the wafer is determined. In general, an EGA (enhanced global alignment) method is used for the fine alignment step. In this method, a plurality of sample shots in the wafer is selected in advance, and the positions of alignment marks (wafer marks) affixed to the sample shots are successively measured. Then, statistical calculation based on, for example, the so-called least square method is performed based on the measurement results and the design values of the shot array to determine all shot array data on the wafer (see, for example, Japanese Unexamined Patent Application Publication No. 61-44429). With this method, it is possible to determine the coordinate positions of the respective shot areas with relatively high accuracy and a high throughput.

[0010]

(4) Next, an exposure step is performed, in which the pattern image of the reticle is transferred onto the wafer via the projection optical system while

successively positioning the respective shot areas on the wafer to be located at exposure positions based on the coordinate positions of the respective shot areas determined by the above-described EGA method or the like and a baseline amount measured in advance.

[0011]

(5) Next, a wafer unload step is performed, in which the wafer on the wafer table having been subjected to the exposure process is unloaded by a wafer unloader. The wafer unload step is performed simultaneously with the wafer load step (1) described above in which the exposure process is performed. That is, a wafer exchange step is constructed by the steps (1) and (5).

[0012]

As described above, in the conventional projection exposure apparatus, roughly, four operations are repeatedly performed by one wafer stage, i.e., wafer exchange → search alignment → fine alignment → exposure → wafer exchange.

[0013]

In addition, the throughput THOR [sheets/hour] of this type of projection exposure apparatus can be expressed by the following expression (1), where it is assumed that the wafer exchange time is T1, the search alignment time is T2, the fine alignment time is T3, and the exposure time is T4.

[0014]

$$THOR=3600/(T1+T2+T3+T4) \quad \text{.........} \quad (1)$$

The operations of T1 to T4 are repeatedly executed successively (sequentially) i.e., T1 → T2 → T3 → T4 → T1. Therefore, if the individual elements T1 to T4 involve high speeds, then the denominator decreases, and the throughput THOR can be improved. However, as for the T1 (wafer exchange time) and the T2 (search

alignment time), since only one operation is performed for one sheet of wafer, the effect of improvement is relatively small. In addition, as for the T3 (fine alignment time), the throughput can be improved if the sampling number of shots is decreased when using the EGA method, or if the measurement time for a single shot is shortened. However, on the contrary, the alignment accuracy will be deteriorated. Therefore, it is impossible to easily shorten T3 without consideration.

[0015]

In addition, the T4 (exposure time) includes the wafer exposure time and the stepping time for movement between the shots. For example, in the case of the scanning projection exposure apparatus based on the step-and-scan method, it is necessary to increase the relative scanning speed between the reticle and the wafer in an amount corresponding to the reduction in the wafer exposure time. However, it is impossible to easily increase the scanning speed without consideration because the synchronization accuracy is deteriorated.

[0016]

In addition, important conditions for this type of projection exposure apparatus other than those concerning the throughput described above include (1) resolution, (2) depth of focus (DOF: Depth of Focus), and (3) line width control accuracy. If it is assumed that the exposure wavelength is λ and the numerical aperture of the projection lens is NA (Numerical Aperture), the resolution R is proportional to λ/NA, and the depth of focus (DOF) is proportional to $\lambda/(NA)^2$.

[0017]

Therefore, in order to improve the resolution R (decrease the value of R), it is necessary to decrease the exposure wavelength λ or increase the numerical aperture NA. Particularly, in recent years, the density of semiconductor devices or the like has

progressed, and the device rule is not more than 0.2 μm L/S (line and space). For this reason, a KrF excimer laser is used as an illumination light source in order to perform exposure for the patterns. However, as described above, the degree of integration of the semiconductor devices will be inevitably increased further in the future. Accordingly, it is desirable to develop an apparatus provided with a light source having a wavelength shorter than that of KrF. As representative examples of candidates for the next-generation apparatus provided with the light source having the shorter wavelength, an apparatus using an ArF excimer laser as its light source and an electron-beam exposure apparatus can be mentioned. However, the apparatus using the ArF excimer laser has numerous technical problems in that light scarcely passes through a place where oxygen is present, it is difficult to provide a high output, the life of the laser is short, and the cost of the apparatus is expensive. In addition, the electron-beam exposure apparatus is inconvenient in that the throughput is extremely low as compared with the light beam exposure apparatus. In fact, the development of the next-generation apparatus, which mainly aims to decrease the wavelength, has not been taken into consideration.

[0018]

As another method of increasing the resolution R, it may be conceivable to increase the numerical aperture NA. However, if NA is increased, there is a demerit in that the DOF of the projection optical system is decreased. The DOF can be roughly classified into UDOF (User Depth of Focus: the part used on the user side: pattern level difference and resist thickness) and the overall focus difference of the apparatus itself. Up to now, since the proportion of UDOF was large, the development of the exposure apparatus has been mainly directed to the policy to

increase DOF. As the technique for increasing the DOF, for example, a modified illumination or the like has been practically used.

[0019]

Incidentally, in order to manufacture a device, it is necessary to form a pattern on a wafer, the pattern composed of a combination of L/S (line and space), isolated L (line), isolated S (space), and CH (contact hole). However, the exposure parameters for performing optimum exposure differ for each pattern shape such as the L/S and isolated line described above. For this reason, in the past, a technique called ED-TREE (except for CH concerning a different reticle) has been used to determine, as a specification of the exposure apparatus, common exposure parameters (for example, coherence factor σ, NA, exposure control accuracy, and reticle drawing accuracy) so that the resolution line width is within a predetermined allowable error with respect to a target value, and a predetermined DOF is obtained. However, it is considered that the following technical trends will appear in the future.

[0020]

(1) In accordance with the improvement in process technology (flatness on the wafer), the pattern level difference and the resist thickness will decrease further, and thus, there is a possibility that the UDOF will decrease, i.e., on the order of 1 μm → 0.4 μm.

[0021]

(2) The exposure wavelength is decreasing, i.e., g-ray (436 nm) → i-ray (365 nm) → KrF (248 nm). However, the future investigation has been made for only a light source based on ArF (193), and the technical hurdle is also high. Thereafter, the progress will proceed to EB exposure.

[0022]

(3) It is expected that the scanning exposures such as those based on the step-and-scan method will be mainly used for the stepper, in place of the stationary exposures such as those based on the step-and-repeat method. This technique makes it possible to perform exposure for a large field with a projection optical system having a small diameter (particularly in the scanning direction), and accordingly, it is easy to realize a high NA.

[0023]

Under the technical trends as described above, the double exposure method is being reviewed as a method for improving the limited resolution. Trials and investigations are being undertaken to use the double exposure for KrF exposure apparatuses, and in the future, to use ArF exposure apparatuses to perform exposure of up to 0.1 μm L/S. In general, the double exposure method is roughly classified into the following three methods.

[0024]

(1) L/S patterns and isolated lines having different exposure parameters are formed on different reticles, and exposure is performed twice on the same wafer under an optimum exposure condition for each reticle.

[0025]

(2) When the phase shift method or the like is introduced, L/S patterns have a higher limiting resolution at the same DOF as compared with the isolated lines. By utilizing this fact, all patterns are formed on the first reticle in L/S patterns, and the L/S patterns are thinned out from the second reticle to form the isolated lines.

[0026]

(3) In general, a higher resolution can be obtained with the isolated lines at a small NA as compared with the L/S patterns (however, DOF is decreased).

Accordingly, all patterns are formed in isolated lines, and L/S patterns are formed by a combination of the isolated lines, which are formed using the first and second reticles..

[0027]

The double exposure method described above has two effects, i.e., improvement in resolution and improvement in DOF.

[0028]

However, in the double exposure method, it is necessary to perform the exposure process several times using a plurality of reticles. Therefore, there are disadvantages in that the exposure time (T4) is not less than twice that of the conventional apparatus, and the throughput is greatly deteriorated. For this reason, in practice, the double exposure method has not been investigated particularly seriously. The improvement in resolution and depth of focus (DOF) has been hitherto made by means of, for example, the use of an ultraviolet exposure wavelength, modified illumination, and phase shift reticle.

[0029]

However, the use of the double exposure method described above in the KrF and ArF exposure apparatuses enables realization of exposure of up to 0.1 μm L/S. Therefore, there is no doubt that the double exposure method is a promising choice for development of the next-generation apparatus aimed at mass-production of 256 M and 1 G DRAMs. For this reason, the development of new techniques for improving the throughput which is a bottleneck problem of the double exposure method has been expected.

[0030]

In this context, if two or more of the four operations, i.e., the wafer exchange, the search alignment, the fine alignment, and the exposure operations can be processed in parallel simultaneously, it may be possible to improve the throughput as compared with the case where the four operations are performed sequentially. For this purpose, it should be premised that a plurality of substrate stages is provided, and this seems to be easy from a theoretical viewpoint. However, in fact, there are numerous problems which should be solved in order to produce a sufficient effect by providing a plurality of substrate stages. For example, if two substrate stages having a size equivalent to that of an existing substrate stage are merely arranged in tandem, there is an inconvenience in that the installation area (so-called footprint) of the apparatus is remarkably increased, resulting in an increase in the cost of the clean room in which the exposure apparatus is placed. In addition, in order to realize highly accurate overlay, it is necessary to execute alignment for the sensitive substrate on the same substrate stage, then execute positioning between the pattern image on the mask and the sensitive substrate by using the alignment result, and then perform exposure. Therefore, the use of only two substrate stages, for example, in which one is exclusively used for exposure, and the other exclusively used for alignment, cannot be said to be a practical countermeasure.

[0031]

The present invention has been made under the circumstances described above, and a first object of the invention is to provide a projection exposure apparatus which is capable of improving the throughput through parallel processing, for example, of the exposure operation and the alignment operation and achieving miniaturization and weight-reduction of the substrate stage.

[0032]

A second object of the invention is to provide a projection exposure method which is capable of improving the throughput and achieving miniaturization and weight-reduction of the stage.

[0033]

Means to Solve Problems

The invention described in Claim 1 is an exposure apparatus for exposing sensitive substrates (W1, W2) by projecting an image of a pattern formed on a mask (R) via a projection optical system (PL) onto the sensitive substrates, the projection exposure apparatus including: a first substrate stage (WS1) which is movable on a two-dimensional plane while holding a sensitive substrate (W1); a second substrate stage (WS2) which is movable independently from the first substrate stage (WS1) on the same plane as that for the first substrate stage (WS1) while holding a sensitive substrate (W2); an alignment system (for example, 24a) provided apart from the projection optical system (PL), for detecting a mark on the substrate stage (WS1, WS2) or a mark on the sensitive substrate (W1, W2) held on the substrate stage (WS1, WS2); an interferometer system provided with a first length-measuring axis (BI1X) for always measuring a position of the first substrate stage (WS1) in a direction of a first axis from one side in the direction of the first axis passing through a projection center of the projection optical system (PL) and a detection center of the mark detecting system (24a), a second length-measuring axis (BI2X) for always measuring a position of the second substrate stage (WS2) in the direction of the first axis from the other side in the direction of the first axis, a third length-measuring axis (BI3Y) which perpendicularly intersects the first axis at the projection center of the projection optical system (PL), and a fourth length-measuring axis (BI4Y) which perpendicularly intersects the first axis at the detection center of the alignment system (24a), the

interferometer system measuring two-dimensional positions of the first and second substrate stages (WS1 and WS2), respectively, by the aid of the length-measuring axes (BI1X to BI4Y); and control means (90) for controlling the operations of the two substrate stages (WS1 and WS2) so that a position of a first stage of the first substrate stage (WS1) and the second substrate stage (WS2) is managed based on the use of a measured value obtained by using the third length-measuring axis (BI3Y) of the interferometer system, and during a period in which the sensitive substrate on the first stage is exposed, a positional relationship between an alignment mark on the sensitive substrate held on the second stage of the first substrate stage (WS1) and the second substrate stage (WS2) and a reference point on the second stage is detected based on the use of a detection result obtained by using the alignment system (24a) and a measured value obtained by using the fourth length-measuring axis (BI4Y) of the interferometer system, and then controlling an operation of the second stage so that an interferometer of the third length-measuring axis (BI3Y) is reset to a state in which a position of the second stage can be measured based on the use of a measured value obtained by using the third length-measuring axis (BI3Y), and a reference point on the second stage is positioned at a position at which a positional relationship with a predetermined reference point in a projection area of the projection optical system (PL) can be detected.

[0034]

According to the invention, the positions of the first substrate stage and the second substrate stage in the first axis direction are always measured by the first length-measuring axis and the second length-measuring axis of the interferometer system. Therefore, when the accurate position of any of the substrate stages in the direction perpendicular to the first axis direction is measured, for example, during the

exposure and the measurement of the alignment marks, it is possible to manage the two-dimensional positions of the first and second substrate stages. In this case, the control means controls the two substrate stages so that a position of a first stage of the first substrate stage and the second substrate stage is managed based on the use of a measured value obtained by using the third length-measuring axis of the interferometer system, and during the period when the sensitive substrate on the first stage is exposed, a positional relationship between an alignment mark on the sensitive substrate held on the second stage of the first substrate stage and the second substrate stage and a reference point on the second stage is detected based on the use of a detection result obtained by using the alignment system and a measured value obtained by using the fourth length-measuring axis of the interferometer system. Then, the control means controls an operation of the second stage so that an interferometer of the third length-measuring axis is reset to a state in which a position of the second stage can be measured based on the use of a measured value obtained by using the third length-measuring axis, and a reference point on the second stage is positioned at a position at which a positional relationship with a predetermined reference point in a projection area of the projection optical system can be detected.

[0035]

That is, the control means is capable of controlling the operations of the two substrate stages as follows. The position of the first stage is managed without any Abbe error with respect to the sensitive substrate held on the first stage, based on the use of the measured value obtained by using the third length-measuring axis which perpendicularly intersects the length-measuring axes (the first length-measuring axis and the second length-measuring axis) in the first axis direction at the projection center of the projection optical system. During the period in which the image of the

pattern on the mask is projected through the projection optical system, the positional relationship between the alignment mark on the sensitive substrate held on the second stage and the reference point on the second stage is accurately detected without any Abbe error based on the use of the detection result obtained by using the alignment system and the measured value obtained by using the fourth length-measuring axis which perpendicularly intersects the length-measuring axes in the first axis direction (the first length-measuring axis and the second length-measuring axis) at the detection center of the mark detecting system. Accordingly, it is possible to concurrently perform the exposure operation effected on the first stage and the alignment operation effected on the second stage. Thus, it is possible to improve the throughput.

[0036]

In addition, when the operations for both stages are completed, the control means controls the operation of the second stage so that the interferometer of the third length-measuring axis is reset to a state in which the position of the second stage can be measured based on the use of a measured value obtained by using the third length-measuring axis, and a reference point on the second stage is positioned such that a positional relationship with a predetermined reference point in a projection area of the projection optical system (PL) can be detected. Accordingly, as for the second stage for which the positional relationship between the reference point on the stage and the alignment mark on the sensitive substrate has been measured (the alignment has been completed), the position thereof can be managed based on the use of the measured value obtained by using the third length-measuring axis without any inconvenience, even when the fourth length-measuring axis used during the measurement of the alignment mark falls into an immeasurable state. Therefore, it is possible to detect the positional relationship between the reference point on the second substrate stage and

the predetermined reference point within the projection area of the projection optical system. Moreover, it is possible to perform the exposure while executing the alignment between the projection area of the projection optical system and the sensitive substrate based on the positional relationship, the measurement result of the alignment, and the measured value obtained by using the third length-measuring axis. That is, the position of the second stage during the exposure can be managed by using another length-measuring axis, even when it is impossible to perform the measurement based on the use of the length-measuring axis which has been used to manage the position of the second stage during the alignment. Therefore, it is possible to reduce the size of the reflective surface of the stage for reflecting the interferometer beam for each of the length-measuring axes. Thus, it is possible to miniaturize the substrate stage.

[0037]

The invention described in Claim 2 is the projection exposure apparatus described in Claim 1, characterized in that the apparatus includes another alignment system (24b) having a detection center on the first axis, disposed on a side opposite to the alignment system (24a) with respect to the projection optical system (PL), wherein the interferometer system is provided with a fifth length-measuring axis (BI5Y) which perpendicularly intersects the first axis at the detection center of the other alignment system (24b); and the control means (90) controls the operations of the two substrate stages so that the position of the first stage is managed based on the use of the measured value obtained by using the third length-measuring axis (BI3Y) of the interferometer system, and during the period in which the sensitive substrate on the first stage is exposed, the positional relationship between the alignment mark on the sensitive substrate held on the second stage and the reference point on the second

stage is detected based on the use of a detection result obtained by using the alignment system and a measured value obtained by using the fourth length-measuring axis (BI4Y) of the interferometer system, and then controls the operation of the first stage so that an interferometer of the fifth length-measuring axis (BI5Y) is reset to a state in which the position of the first stage can be measured based on the use of the measured value obtained by using the fifth length-measuring axis (BI5Y), and a reference point on the first stage is positioned at a position within a detection area of the other alignment system (24b).

[0038]

According to the invention, the control means is capable of controlling the operations of the two stages as follows. That is, the position of the first substrate stage is managed without any Abbe error with respect to the sensitive substrate held on the first stage, based on the use of the measured value obtained by using the third length-measuring axis which perpendicularly intersects the length-measuring axes (the first length-measuring axis and the second length-measuring axis) in the first axis direction at the projection center of the projection optical system. During the period in which the image of the pattern formed on the mask is subjected to exposure through the projection optical system, the positional relationship between the alignment point on the sensitive substrate held on the second stage and the reference point on the second stage is accurately detected without any Abbe error based on the use of the detection result obtained by using the alignment system and the measured value obtained by using the fourth length-measuring axis which perpendicularly intersects the length-measuring axes (the first length-measuring axis and the second length-measuring axis) in the first axis direction at the detection center of the alignment system. Accordingly, it is possible to concurrently perform the exposure operation

effected on the first substrate stage and the alignment operation effected on the second stage.

[0039]

In addition, when the operations for both stages are completed, the control means controls the operation of the first stage so that the interferometer of the fifth length-measuring axis is reset to a state in which the position of the first stage can be measured based on the use of a measured value obtained by using the fifth length-measuring axis, and a reference point on the first substrate stage is positioned at a position within a detection area of the other alignment system. Accordingly, as for the first stage for which the exposure for the sensitive substrate has been completed, the position thereof can be managed without any Abbe error, based on the use of the reference point on the first substrate stage and the measured value obtained by using the fifth length-measuring axis which perpendicularly intersects the length-measuring axis (the first length-measuring axis and the second length-measuring axis) in the first axis direction at the detection center of the other alignment system without any inconvenience, even when the third length-measuring axis used during the exposure falls into an immeasurable state. In addition, the position of the reference point on the first substrate stage and the position of the alignment mark of the sensitive substrate held on the first stage can be measured continuously to the exposure. Therefore, the exposure operation effected on the first stage and the exposure operation effected on the second stage can be easily changed by shifting the two substrate stages in the first axis direction so that the interferometer of the third length-measuring axis is reset to a state in which the position of the second substrate stage, for which the alignment operation has been completed, can be measured based on the use of the measured value obtained by the third length-measuring axis, and the interferometer of the fifth

length-measuring axis is reset to a state in which the position of the first stage, for which the exposure operation has been completed, can be measured based on the use of the measured value obtained by the fifth length-measuring axis.

[0040]

In this case, similar to the invention described in Claim 3, when the apparatus further includes a transport system (180 to 200) for performing delivery of the sensitive substrate (W1, W2) between the first substrate stage (WS1) and the second substrate stage (WS2), it is desirable that the control means controls the delivery of the substrate between the first stage and the transport system (180 to 200) to be performed in a state in which the reference point of the first substrate stage is positioned at a position within the detection area of the other alignment system (24b). In this case, in addition to the change between the exposure operation and the alignment operation described above, the control means resets the fifth length-measuring axis of the interferometer system and allows the substrate to be delivered between the first stage and the transport system in the state in which the reference point on the first substrate stage is positioned within the detection area of the other alignment system. Accordingly, the measurement of the position of the reference point as the operation to start the alignment and the exchange of the sensitive substrates can be performed in a stationary state of the substrate stage. In addition to the fact that the movement time required for the substrate stage to move from the substrate exchange position to the alignment start position is zero, it is possible to perform the operations described above concerning the time T1, the time T2, and the time T3 on the side of the first substrate stage, while performing the operation concerning the time T4 on the side of the second substrate stage. Therefore, it is

possible to further improve the throughput as compared with the case of the invention described in Claim 2.

[0041]

The invention described in Claim 4 is the projection exposure apparatus described in Claim 1, characterized in that reference marks (MK1, MK2, MK3) as the reference points of the stages are formed on the first substrate stage (WS1) and the second substrate stage (WS2), respectively; a predetermined reference point within the projection area of the projection optical system (PL) is the projection center of the pattern image of the mask (R); and the apparatus further includes mark position detection means (142, 144) for detecting a relative positional relationship between the projection center of the pattern image of the mask (R) and the reference marks PL on the stages via the mask (R) and the projection optical system.

[0042]

According to the invention, the control means is capable of controlling the operations of the two substrate stages so that the position of the first stage with respect to the sensitive substrate held on the first stage is managed without any Abbe error based on the use of a measured value obtained by using the third length-measuring axis, and during the period when the pattern image of the mask is exposed via the projection optical system, the positional relationship between the alignment mark on the sensitive substrate held on the second stage and the reference mark (MK2) on the second stage is accurately detected without any Abbe error based on the use of the detection result obtained by using the alignment system (24a) and the measured value obtained by using the fourth length-measuring axis. Accordingly, it is possible to concurrently perform the exposure operation effected on the first substrate stage and the alignment operation effected on the second stage.

[0043]

In addition, when the operations for both stages are completed, the control means controls the operation of the second stage so that the interferometer of the third length-measuring axis is reset to a state in which the position of the second stage can be measured based on the use of a measured value obtained by using the third length-measuring axis, and the reference point (MK1, MK3) on the second stage is positioned at a position at which a positional relationship with the projection center of the pattern image of the mask can be detected. Accordingly, as for the second stage for which the positional relationship between the reference point (MK2) on the stage and the alignment mark on the sensitive substrate has been measured, the position thereof can be managed based on the use of the measured value obtained by using the third length-measuring axis without any inconvenience, even when the fourth length-measuring axis used during the measurement of the alignment mark falls into an immeasurable state. In addition, it is possible to detect the relative positional relationship between the reference point (MK1, MK3) on the second substrate stage and the projection center of the pattern image of the mask by using the mark position detection means (142, 144) for detecting the positional relationship via the mask (R) and the projection optical system (PL). Therefore, it is possible to perform the exposure while executing the alignment between the pattern image of the mask and the sensitive substrate by using the projection optical system (PL) based on the positional relationship, the measurement result of the alignment, and the measured value obtained by using the third length-measuring axis.

[0044]

The invention described in Claim 5 is a projection exposure method for exposing sensitive substrates (W1, W2) by projecting an image of a pattern formed on

a mask (R) via a projection optical system (PL) onto the sensitive substrates, characterized in that the method includes: preparing two substrate stages (WS1, WS2), each of which is movable independently on the same plane while holding a sensitive substrate (W1, W2); exposing a sensitive substrate held on one of the two stages by projecting the pattern image on the mask onto the sensitive substrate while measuring a position of the first stage by using a predetermined interferometer, and during a period when the substrate held on the first stage is exposed, measuring a positional relationship between an alignment mark on a sensitive substrate held on the other one of the two stages and a reference point on the second stage while measuring a position of the second stage by using another interferometer different from the predetermined interferometer; after the exposure for the sensitive substrate held on the first stage is completed, resetting the predetermined interferometer to a state in which the position of the second stage can be measured by the predetermined interferometer, and positioning a reference point of the second stage to a position at which a positional relationship with a predetermined reference point within a projection area of the projection optical system can be detected; and performing alignment between the sensitive substrate held on the second stage and the pattern image of the mask by using the predetermined interferometer being reset based on the measured positional relationship.

[0045]

According to the invention, the exposure operation for the sensitive substrate held on the first stage can be performed concurrently with the measurement (alignment operation) of the positional relationship between the alignment mark of the sensitive substrate held on the second stage and the reference point on the stage. In this case, the position of the first stage is managed by the predetermined

interferometer, and the position of the second stage is managed by the other interferometer. When the exposure operation on the first stage side is completed, the predetermined interferometer is reset to a state in which the position of the second stage can be measured by the predetermined interferometer which has hitherto been used to manage the position of the first stage. The reference point of the second stage is positioned at a position at which the positional relationship with the predetermined reference point within the projection area of the projection optical system can be measured. Subsequently, based on the positional relationship between the alignment mark on the sensitive substrate held on the second stage which has been measured earlier and the reference point on the second stage, the alignment between the sensitive substrate held on the second stage and the pattern image of the mask is performed by the predetermined interferometer being reset, and the pattern image of the mask is projected onto the sensitive substrate, thus exposing the sensitive substrate.

[0046]

That is, the exposure operation for the sensitive substrate held on the first substrate stage and the alignment operation for the sensitive substrate held on the second stage are concurrently performed. After that, the first substrate stage is retracted to a predetermined substrate exchange position, concurrently with which the second stage is moved toward the projection optical system. When the second stage is moved to a position at which the position thereof can be measured by the predetermined interferometer, the predetermined interferometer is reset, and the reference point of the second stage is positioned at a position at which the positional relationship with the predetermined reference point (for example, the projection center of the pattern image of the mask) within the projection area of the projection optical

system can be detected. When the positional relationship between them is detected, the alignment is performed for the sensitive substrate held on the second stage and the pattern image of the mask based on the detection result and the positional relationship between the alignment mark and the reference point on the stage previously measured during the alignment operation, while the position of the second stage is managed by using the predetermined interferometer.

[0047]

Therefore, it is possible to improve the throughput by concurrently performing the exposure operation for the sensitive substrate on the first substrate stage and the alignment operation for the sensitive substrate on the second substrate stage. Even when the other interferometer, which has been used to manage the position of the second stage during the alignment, cannot be used for the measurement, it is possible to manage the position of the second stage during the exposure by using the predetermined interferometer. Therefore, it is possible to reduce the size of the reflective surface of the stage for reflecting the interferometer beam of each of the interferometers, and accordingly, to miniaturize the substrate stage.

[0048]

The invention described in Claim 6 is a projection exposure apparatus for exposing sensitive substrates (W1, W2) by projecting an image of a pattern formed on a mask (R) via a projection optical system (PL) onto the sensitive substrates, the projection exposure apparatus including: a first substrate stage (WS1) which is movable on a two-dimensional plane while holding a sensitive substrate (W1); a second substrate stage (WS2) which is movable independently from the first substrate stage (WS1) on the same plane as that for the first substrate stage (WS1) while holding a sensitive substrate (W2); an alignment system (for example, 24a) provided

apart from the projection optical system (PL), for detecting a reference mark on the substrate stage (WS1, WS2) and a mark on the sensitive substrate held on the substrate stage; an interferometer system provided with a first length-measuring axis (BI1X) for measuring a position of the first substrate stage (WS1) in a direction of a first axis from one side in the direction of the first axis passing through a projection center of the projection optical system (PL) and a detection center of the mark detecting system (24a), a second length-measuring axis (BI2X) for measuring a position of the second substrate stage (WS2) in the direction of the first axis from the other side in the direction of the first axis, a third length-measuring axis (BI3Y) which perpendicularly intersects the first axis at the projection center of the projection optical system (PL), and a fourth length-measuring axis (BI4Y) which perpendicularly intersects the first axis at the detection center of the alignment system (24a), the interferometer system measuring two-dimensional positions of the first and second substrate stages (WS1 and WS2), respectively, by the aid of the length-measuring axes (BI1X to BI4Y); and control means (90) for managing a position of a first stage of the first substrate stage (WS1) and the second substrate stage (WS2) by using the third length-measuring axis (BI3Y) of the interferometer system, managing a position of the second stage by using the fourth length-measuring axis (BI4Y) during a period in which a sensitive substrate on the first stage is exposed, and calculating a positional relationship between a mark on the sensitive substrate held on the second stage and a reference mark on the second stage by using the alignment system (24a), the control means managing the position of the second stage by using the third length-measuring axis (BI3Y) after the exposure for the sensitive substrate held on the first stage is completed, and calculating a positional relationship between a projection position of

the pattern image of the mask by the projection optical system (PL) and the reference mark on the second stage.

[0049]

According to the invention, the control means manages the position of a first stage of the first substrate stage and the second substrate stage based on the use of the measured value obtained by using the third length-measuring axis of the interferometer system, and calculates the positional relationship between a mark on the sensitive substrate held on the second stage and a reference mark on the second stage by using the alignment system during the period in which the sensitive substrate on the first stage is exposed. The control means also manages the position of the second stage by using the third length-measuring axis after the exposure for the sensitive substrate held on the first stage is completed, thus calculating the positional relationship between a projection position of the pattern image of the mask by the projection optical system and the reference mark on the second stage.

[0050]

That is, the control means manages the position of the first stage without any Abbe error with respect to the sensitive substrate held on the first stage, based on the use of the measured value obtained by using the third length-measuring axis which perpendicularly intersects the length-measuring axes (the first length-measuring axis and the second length-measuring axis) in the first axis direction at the projection center of the projection optical system. During the period in which the pattern image of the mask is projected through the projection optical system, the positional relationship between the mark on the sensitive substrate held on the second stage and the reference mark on the second stage is accurately detected without any Abbe error based on the use of the detection result obtained by using the alignment system and

the measured value obtained by using the fourth length-measuring axis which perpendicularly intersects the length-measuring axes in the first axis direction (the first length-measuring axis and the second length-measuring axis) at the detection center of the mark detecting system. Accordingly, it is possible to concurrently perform the exposure operation effected on the first substrate stage and the alignment operation effected on the second stage. Thus, it is possible to improve the throughput.

[0051]

In addition, when the exposure for the sensitive substrate held on the first stage is completed, namely when the operations for both stages are completed, the control means calculates the positional relationship between the projection position of the pattern image of the mask by the projection optical system and the reference mark on the second stage while managing the position of the second stage by using the third length-measuring axis. Accordingly, as for the second stage for which the positional relationship between the reference point on the stage and the alignment mark on the sensitive substrate has been measured (the alignment has been completed), the position thereof can be managed based on the use of the measured value obtained by using the third length-measuring axis without any inconvenience, even when the fourth length-measuring axis used during the measurement of the alignment mark falls into an immeasurable state. Therefore, it is possible to calculate the positional relationship between the reference mark on the second stage and the projection position of the pattern image of the mask. Moreover, it is possible to perform the exposure while executing the alignment between the projection area of the projection optical system and the sensitive substrate based on the positional relationship, the measurement result of the alignment, and the measured value obtained by using the third length-measuring axis. That is, the position of the second stage during the

exposure can be managed by using another length-measuring axis, even when it is impossible to perform the measurement based on the use of the length-measuring axis which has been used to manage the position of the second stage during the alignment. Therefore, it is possible to reduce the size of the reflective surface of the stage for reflecting the interferometer beam for each of the length-measuring axes. Thus, it is possible to miniaturize the substrate stage.

[0052]

In this case, similar to the invention described in Claim 7, after the sensitive substrate held on the first stage is exposed, and when the positional relationship between the projection position of the pattern image of the mask (R) by the projection optical system (PL) and the reference mark on the second stage is calculated, the measured value obtained by using the third length-measuring axis (BI3Y) of the interferometer system may be reset.

[0053]

The invention described in Claim 8 is the projection exposure apparatus described in Claim 6, characterized in that the control means (90) executes exposure for the sensitive substrate held on the second stage while controlling the position of the second stage based on the positional relationship between the mark on the sensitive substrate held on the second stage and the reference mark on the second stage and the measurement result obtained by using the third length-measuring axis when the positional relationship between the projection position of the pattern image of the mask by the projection optical system and the reference mark on the second stage is calculated.

[0054]

According to the invention, the exposure for the sensitive substrate held on the second stage is performed while the position of the second stage is controlled based on the positional relationship (calculated by the same sensor, namely the alignment system) between the mark on the sensitive substrate held on the second stage and the reference mark on the second stage, and the measurement result obtained by using the third length-measuring axis when the positional relationship between the projection position of the pattern image of the mask by the projection optical system and the reference mark on the second stage is calculated. Therefore, after the positional relationship between the mark on the sensitive substrate held on the second stage and the reference mark on the second stage is calculated, and when the fourth length-measuring axis, which has been used to manage the position of the second stage when the positional relationship is calculated, cannot be used for the measurement, it is possible to position the sensitive substrate to the exposure position with high accuracy during the exposure without causing any inconvenience.

[0055]

In this case, similar to the invention described in Claim 9, it is desirable that the control means (90) performs positioning of the second stage so that the reference mark on the second stage falls within the detection area of the alignment system after the sensitive substrate held on the second stage is exposed and then performs exchange of the sensitive substrates.

[0056]

In this case, the control unit performs the exchange of the substrate on the second stage in a state in which the reference mark on the second substrate stage is positioned to be within the detection area of the alignment system. Accordingly, the operation to start the alignment and the exchange of the sensitive substrates can be

performed in a stationary state of the substrate stage. In addition to the fact that the movement time required for the substrate stage to move from the wafer exchange position to the alignment start position is zero, it is possible to perform the operations described above concerning the time T1, the time T2, and the time T3 on the side of the second substrate stage, while performing the operation concerning the time T4 on the side of the first substrate stage. Therefore, it is possible to further improve the throughput.

[0057]

In addition, in this case, similar to the invention described in Claim 10, a measured value obtained by using the fourth length-measuring axis of the interferometer system may be reset when the reference mark on the second stage is detected by using the alignment system.

[0058]

The invention described in Claim 11 is a projection exposure apparatus for exposing sensitive substrates (W) by projecting an image of a pattern formed on a mask (R) via a projection optical system (PL) onto the sensitive substrates, characterized in that the apparatus includes: a first substrate stage (WS1) which is movable on a two-dimensional plane while holding a sensitive substrate (W1); a second substrate stage (WS2) which is movable independently from the first substrate stage (WS1) on the same plane as that for the first substrate stage (WS1) while holding a sensitive substrate (W2); a transport system (180 to 200) for delivering the sensitive substrate between the first substrate stage (WS1) and the second substrate stage (WS2); an alignment system (for example, 24a) provided apart from the projection optical system (PL), for detecting the reference mark on the substrate stage or a mark on the sensitive substrate held on the substrate stage; and control means

(90) for controlling the two substrate stages so that the second stage performs an exposure operation during a period in which one stage of the first substrate stage (WS1) and the second substrate stage (WS2) performs the delivery of the sensitive substrate with respect to the transport system (180 to 200), wherein the control means (90) controls the first stage so that the reference mark on the first stage falls within a detection area of the alignment system when the first stage performs the delivery of the sensitive substrate with respect to the transport system.

[0059]

According to the invention, the control means controls the operations of both stages so that the second stage performs the exposure operation during a period in which a first stage of the first substrate stage and the second substrate stage performs the delivery of the sensitive substrate with respect to the transport system. Therefore, the operation described above concerning the time T1 can be processed concurrently with the operation concerning the time T4. In addition, the control unit controls the first stage so that the reference mark on the first stage falls within the detection area of the alignment system when the first stage performs the delivery of the sensitive substrate with respect to the transport system. Accordingly, the measurement of the position of the reference point as the operation to start the alignment and the exchange of the sensitive substrates can be performed in a stationary state of the substrate stage. In addition to the fact that the movement time required for the substrate stage to move from the substrate exchange position to the alignment start position is zero, it is possible to perform the operations described above concerning the time T1, the time T2, and the time T3 on the side of the first substrate stage, while performing the operation concerning the time T4 on the side of the second substrate stage. Thus, it is

possible to improve the throughput as compared with the conventional sequential process which requires the time (T1+T2+T3+T4).

[0060]

Embodiments of the Invention

First Embodiment

Hereinafter, the first embodiment of the present invention will be described with reference to FIGS. 1 to 15.

[0061]

In FIG. 1, a schematic arrangement of a projection exposure apparatus 10 according to one embodiment is shown. The projection exposure apparatus 10 is a projection exposure apparatus of the scanning exposure type based on the so-called step-and-scan method.

[0062]

The projection exposure apparatus 10 includes, for example, a stage apparatus provided with wafer stages WS1 and WS2 as first and second substrate stages which are independently movable in the two-dimensional directions on a base pedestal 12 while holding wafers W1 and W2 as sensitive substrates, a projection optical system PL disposed over the stage apparatus, a reticle driving mechanism disposed over the projection optical system PL, for driving a reticle R as a mask in a predetermined direction, i.e., in the Y-axis direction in this embodiment (direction perpendicular to the plane of the paper in FIG. 1), an illumination system for illuminating the reticle R from a position thereover, and a control system for controlling the respective components.

[0063]

The stage apparatus is supported over the base pedestal 12 in a floating manner by the aid of an air bearing (not shown in the figures). The stage apparatus includes the two wafer stages WS1 and WS2 which are independently movable two-dimensionally in the X-axis direction (lateral direction along the plane of the paper shown in FIG. 1) and in the Y-axis direction (direction perpendicular to the plane of the paper shown in FIG. 1), a stage-driving system for driving the wafer stages WS1 and WS2, and an interferometer system for measuring the positions of the wafer stages WS1 and WS2.

[0064]

The arrangement will be further described below. Air pads (not shown in the figures), for example, vacuum-pre-loadable air bearings, are provided at a plurality of positions on the bottom surfaces of the wafer stages WS1 and WS2. The wafer stages WS1 and WS2 are supported over the base pedestal 12 in a floating manner in a state in which a spacing distance of, for example, several microns is maintained in accordance with the balance between the vacuum-pre-loaded force and the air-ejecting force effected by the air pads.

[0065]

As shown in a plan view in FIG. 3, two X-axis linear guides (for example, fixed magnets of a linear motor of the so-called moving coil type) 122 and 124, which extend in the X-axis direction, are provided in parallel on the base pedestal 12. Two pairs of movable members 114 and 118, and 116 and 120, which are movable along the X-axis linear guides, respectively, are attached to the X-axis linear guides 122 and 124, respectively. Driving coils (not shown in the figures) are attached to bottom portions of the four movable members 114, 118, 116, 120, respectively, so that the X-axis linear guide 122 or 124 is surrounded thereby from the upper and lateral sides.

The moving coil type linear motors for driving the respective movable members 114, 116, 118, and 120 in the X-axis direction are constructed by the driving coils and the X-axis linear guide 122 or 124. However, in the following description, the movable members 114, 116, 118, and 120 will be referred to as "X-axis linear motors" for convenience.

[0066]

Among them, the two X-axis linear motors 114 and 116 are provided at both ends of a Y-axis linear guide 110 extending in the Y-axis direction (for example, a fixed coil of a linear motor of the moving magnet type), respectively. The other two X-axis linear motors 118 and 120 are secured to both ends of a similar Y-axis linear guide 112 extending in the Y-axis direction. Therefore, the Y-axis linear guide 110 is driven along the X-axis linear guides 122 and 124 by means of the X-axis linear motors 114 and 116, while the Y-axis linear guide 112 is driven along the X-axis linear guides 122 and 124 by means of the X-axis linear motors 118 and 120.

[0067]

On the other hand, a magnet (not shown in the figures), which surrounds one of the Y-axis linear guides 110 from the upper and lateral sides, is provided on the bottom of the wafer stage WS1. A moving magnet type linear motor for driving the wafer stage WS1 in the Y-axis direction is constructed by the magnet and the Y-axis linear guide 110. In addition, another magnet (not shown in the figures), which surrounds the other Y-axis linear guide 112 from the upper and lateral sides, is provided on the bottom of the wafer stage WS2. A moving magnet type linear motor for driving the wafer stage WS2 in the Y-axis direction is constructed by the magnet and the Y-axis linear guide 112.

[0068]

That is, in the present embodiment, the stage-driving system for two-dimensionally driving the wafer stages WS1 and WS2 independently in the XY directions is constructed, for example, by the X-axis linear guides 122 and 124, the X-axis linear motors 114, 116, 118, and 120, the Y-axis linear guides 110 and 112, and the unillustrated magnets disposed on the bottoms of the wafer stages WS1 and WS2. The stage-driving system is controlled by a stage control unit 38 shown in FIG. 1.

[0069]

Minute yawing can be generated on the wafer stage WS1, or removed therefrom, by slightly varying the torque of the pair of X-axis linear motors 114 and 116 provided at both ends of the Y-axis linear guide 110. Similarly, minute yawing can be generated on the wafer stage WS2, or removed therefrom, by slightly varying the torque of the pair of X-axis linear motors 118 and 120 provided at both ends of the Y-axis linear guide 112.

[0070]

Wafers W1 and W2 are fixed on the wafer stages WS1 and WS2 by means of, for example, vacuum suction by the aid of unillustrated wafer holders. Each of the wafer holders is finely driven in the Z-axis direction perpendicular to the XY plane and in the θ direction (rotational direction about the Z-axis) by means of an unillustrated Z·θ driving mechanism. In addition, fiducial mark plates FM1 and FM2, on which various fiducial marks are formed, are placed on the upper surfaces of the wafer stages WS1 and WS2 to be at substantially the same height as that of the wafers W1 and W2, respectively. The fiducial mark plates FM1 and FM2 are used, for example, when the reference position of each of the wafer stages is detected.

[0071]

In addition, one side surface (left side surface in FIG. 1) 20 of the wafer stage WS1 in the X-axis direction, and one side surface (back surface as viewed in the plane of the paper in FIG. 1) 21 thereof in the Y-axis direction are mirror-finished reflective surfaces. Similarly, the other side surface (right side surface in FIG. 1) 22 of the wafer stage WS2 in the X-axis direction, and one side surface 23 thereof in the Y-axis direction are mirror-finished reflective surfaces. Interferometer beams for respective length-measuring axes for constructing an interferometer system to be described later are projected onto the reflective surfaces. Reflected light beams therefrom are received by respective interferometers so as to measure displacements of the respective reflective surfaces from the reference position (in general, a fixed mirror is disposed on a side surface of the projection optical system or on a side surface of the alignment optical system, and such a position is used as the reference surface). Thus, the two-dimensional positions of the wafer stages WS1 and WS2 are measured, respectively. The construction of the length-measuring axes of the interferometer system will be described in detail later.

[0072]

In this case, a refractive optical system, which includes a plurality of lens elements having a common optical axis in the Z-axis direction, and which is telecentric on both sides and has a predetermined reduction ratio, for example, 1/5, is used as the projection optical system PL. Therefore, the speed of movement of the wafer stage in the scanning direction during scanning exposure based on the step-and-scan method is 1/5 of the speed of movement of the reticle stage.

[0073]

As shown in FIG. 1, off-axis type alignment systems 24a and 24b having the same function are installed on both sides in the X-axis direction of the projection

optical system PL at positions separated from the center of the optical axis of the projection optical system PL (coincident with the projection center of the reticle pattern image) by the same distance, respectively. The alignment systems 24a and 24b have three types of alignment sensors based on the LSA (Laser Step Alignment) system, the FIA (Field Image Alignment) system, and the LIA (Laser Interferometric Alignment) system. Thus, it is possible to perform measurement of the two-dimensional positions in the X and Y directions of the reference mark on the fiducial mark plate and the alignment mark on the wafer.

[0074]

Here, the sensor based on the LSA system is a general-purpose sensor which is most widely used to measure the mark position by irradiating the mark with a laser beam and utilizing diffracted and scattered light beams. The sensor based on the LSA system has been hitherto widely used for process wafers. The sensor based on the FIA system is a sensor to measure the mark position by illuminating the mark with a broadband (wide-zone) light beam, for example, of a halogen lamp and performing image processing for an obtained mark image. The sensor based on the FIA system is effectively used for asymmetric marks on aluminum layers and wafer surfaces. In addition, the sensor based on the LIA system is a sensor to detect positional information of the mark from a phase measured by irradiating a diffraction grating-shaped mark with laser beams having slightly different frequencies from two directions, and interfering two generated diffracted light beams. The sensor based on the LIA system is effectively used for wafers having a small level difference and wafers having a rough surface.

[0075]

In the present embodiment, the three types of alignment sensors are appropriately used depending on the purpose so that, for example, the so-called search alignment is performed for measuring the approximate position of the wafer by detecting the positions of three points of a one-dimensional mark on the wafer, and fine alignment is performed for measuring the accurate positions of shot areas on the wafer.

[0076]

In this case, the alignment system 24a is used, for example, to measure the positions of the alignment marks on the wafer W1 held on the wafer stage WS1 and the reference marks formed on the fiducial mark plate FM1. In addition, the alignment system 24b is used, for example, to measure the positions of the alignment marks on the wafer W2 held on the wafer stage WS2 and the reference marks formed on the fiducial mark plate FM2.

[0077]

The information supplied from the respective alignment sensors for constructing the alignment systems 24a and 24b, is subjected to A/D conversion by an alignment control unit 80 to obtain a digitalized waveform signal which is computed and processed to detect the mark position. The detection results are supplied to a main control unit 90. The main control unit 90 instructs the stage control unit to perform, for example, correction for the synchronization position during the exposure in accordance with the results.

[0078]

In addition, in the exposure apparatus 10 of the present embodiment, although not shown in FIG. 1, a pair of reticle alignment microscopes 142 and 144 serving as mark position detecting means is provided over the reticle R as shown in FIG. 5.

Each of the reticle alignment microscopes 142 and 144 includes a TTR (Through The Reticle) alignment optical system using an exposure wavelength for simultaneously observing the reticle mark (not shown) on the reticle R and the marks on the fiducial mark plates FM1 and FM2 via the projection optical system PL. Detection signals obtained by the reticle alignment microscopes 142 and 144 are supplied to the main control unit 90. In this case, polarizing mirrors 146 and 148 for introducing detected light beams from the reticle R into the reticle alignment microscopes 142 and 144, respectively, are movably arranged. When the exposure sequence is started, the polarizing mirrors 146 and 148 are retracted by means of mirror-drivers (not shown in the figures) in accordance with the command supplied from the main control unit 90, respectively. A construction equivalent to the reticle alignment microscopes 142 and 144 is disclosed, for example, in Japanese Unexamined Patent Application Publication No. 7-176468.

[0079]

In addition, although not shown in FIG. 1, autofocus/autoleveling measuring mechanisms (hereinafter referred to as "AF/AL system") 130, 132, and 134 for investigating the focusing position are provided for the projection optical system PL and the alignment systems 24a and 24b, respectively, as shown in FIG. 4. Among them, the AF/AL system 132 is provided to detect whether or not the exposure surface of the wafer W coincides with (focuses with) the image plane of the projection optical system PL within a range of the depth of focus, because it is necessary that the pattern formation plane on the reticle R is conjugate to the exposure surface of the wafer W in relation to the projection optical system PL in order to accurately transfer the pattern on the reticle R onto the wafer (W1 or W2) by means of scanning exposure. In the

present embodiment, a so-called multi-point AF system is used as the AF/AL system 132.

[0080]

Now, detailed arrangement of the multi-point AF system for constructing the AF/AL system 132 will be described with reference to FIGS. 5 and 6.

[0081]

As shown in FIG. 5, the AF/AL system (multi-point AF system) 132 includes an irradiating optical system 151 including a bundle of optical fibers 150, a light-collecting lens 152, a pattern formation plate 154, a lens 156, a mirror 158, and an irradiating objective lens 160; and a light-collecting optical system 161 including a light-collecting objective lens 162, a rotary directional vibration plate 164, an image-forming lens 166, and a light receiving unit 168.

[0082]

The respective constituent components of the AF/AL system (multi-point AF system) 132 will be now described together with their functions.

[0083]

An illumination light beam having a wavelength which is different from that of the exposure light beam EL and at which the photoresist on the wafer W1 (or W2) is not photosensitive is introduced from an unillustrated illumination light source via the optical fiber bundle 150. The illumination light beam radiated from the optical fiber bundle 150 passes through the light-collecting lens 152, and the pattern formation plate 154 is illuminated therewith. The illumination light beam transmitted through the pattern formation plate 154 passes through the lens 156, the mirror 158, and the irradiating objective lens 160, and the illumination light beam is projected onto the exposure surface of the wafer W. The image of the pattern on the pattern

formation plate 154 is projected obliquely with respect to the optical axis AX, and the image is formed on the exposure surface of the wafer W1 (or W2). The illumination light beam is reflected by the wafer W1, and it is projected onto the light receiving surface of the light receiving unit 168 via the light-collecting objective lens 162, the rotary directional vibration plate 164, and the image-forming lens 166. The image of the pattern on the pattern formation plate 154 is formed again on the light receiving surface of the light receiving unit 168. The main control unit 90 is now operated to give predetermined vibration to the rotary-directional vibration plate 164 by the aid of a vibrating unit 172. In addition, the main control unit 90 supplies, to a signal processing unit 170, detection signals from a large number of light receiving elements of the light receiving unit 168 (specifically, the number is the same as that of slit patterns on the pattern formation plate 154). In addition, the signal processing unit 170 performs synchronized detection for the respective detection signals by the driving signal of the vibrating unit 172 to obtain a large number of focus signals which are supplied to the main control unit 90 via the stage control unit 38.

[0084]

In this case, as shown in FIG. 6, a slit-shaped aperture pattern 93-11 to 93-59, which includes, for example, 5×9=45 individuals, is formed vertically on the pattern formation plate 154. The image of the slit-shaped aperture pattern is projected obliquely (at 45°) with respect to the X-axis and the Y-axis, onto the exposure surface of the wafer W. As a result, as shown in FIG. 4, the slit images are formed, which are arranged in a matrix, and inclined at 45° with respect to the X-axis and the Y-axis. Reference symbol IF in FIG. 4 indicates an illumination field on the wafer that is conjugate to the illumination area on the reticle illuminated by the illumination system. As will be clear from FIG. 4, the detecting beam is radiated onto two-

dimensional area which is sufficiently larger than the illumination field IF under the projection optical system PL.

[0085]

The other AF/AL systems 130 and 134 are constructed in the same manner as the AF/AL system 132. That is, the present embodiment is constructed such that approximately the same area as that for the AF/AL system 132 used to detect the focus during exposure can also be irradiated with the detecting beam by the AF/AL mechanisms 130 and 134 used when the alignment mark is measured. For this reason, highly accurate alignment measurement can be performed by measuring the position of the alignment mark while executing the autofocus/autoleveling based on the use of the measurement and control of the AF/AL system similar to those performed during exposure, upon measurement by the alignment sensors based on the use of the alignment systems 24a and 24b. In other words, no offset (error) occurs due to a change in the posture of the stage between the process of exposure and the process of alignment.

[0086]

Next, the reticle driving mechanism will be described with reference to FIGS. 1 and 2.

[0087]

The reticle driving mechanism includes a reticle stage RST which is movable in the XY two-dimensional directions over a reticle base plate 32 while holding the reticle R, a linear motor (not shown in the figures) for driving the reticle stage RST, and a reticle interferometer system for managing the position of the reticle stage RST.

[0088]

The arrangement of the reticle driving mechanism will be described in further detail below. As shown in FIG. 2, the reticle stage RST is constructed such that two sheets of reticles R1 and R2 are placed in series in the scanning direction (Y-axis direction). The reticle stage RST is supported in a floating manner over the reticle base plate 32 by the aid of, for example, an unillustrated air bearing. The reticle stage RST is subjected to fine driving in the X-axis direction, minute rotation in the θ direction, and scanning driving in the Y-axis direction by the aid of a driving mechanism 30 (see FIG. 1) including, for example, an unillustrated linear motor. The driving mechanism 30 is a mechanism which uses a linear motor similar to the stage apparatus described above as a driving source. However, the driving mechanism 30 is indicated as a simple block in FIG. 1 for illustrative and explanatory purposes. Accordingly, the reticles R1 and R2 on the reticle stage RST are selectively used, for example, upon double exposure, in which each of the reticles can be subjected to scanning in synchronization with the wafer.

[0089]

A parallel flat plate movement mirror 34, which is composed of the same material (for example, a ceramic) as that of the reticle stage RST, is provided at an end on one side in the X-axis direction on the reticle stage RST to extend in the Y-axis direction. A reflective surface, which is formed by means of mirror-finish processing, is formed on one side surface of the movement mirror 34 in the X-axis direction. An interferometer beam is radiated onto the reflective surface of the movement mirror 34 from the interferometer indicated by the length-measuring axis BI6X for constructing the interferometer system 36 shown in FIG. 1. The reflected light beam is received by the interferometer to measure the relative displacement with respect to the reference plane in the same manner as performed for the wafer stage.

Thus, the position of the reticle stage RST is measured. In this case, the interferometer having the length-measuring axis BI6X actually has two interferometer optical axes capable of performing measurement independently, and it is thus possible to measure the position of the reticle stage in the X-axis direction and measure the yawing amount. The interferometer having the length-measuring axis BI6X is used to perform synchronization control in the X direction and rotational control of the reticle stage RST in the direction to cancel the relative rotation (rotational error) between the reticle and the wafer based on the information on the X position and the information on the yawing of the wafer stages WS1 and WS2 supplied from the interferometers 16 and 18 having length-measuring axes BI1X, BI2X disposed on the wafer stage side, which will be described later.

[0090]

On the other hand, a pair of corner cube mirrors 35 and 37 is installed on the other side (front side in the plane of the paper in FIG. 1) of the reticle stage RST in the Y-axis direction which is the scanning direction. Interferometer beams, which are represented by length-measuring axes BI7Y and BI8Y in FIG. 2, are radiated from a pair of double-path interferometers (not shown in the figures) onto the corner cube mirrors 35 and 37. The beams are returned to the reflective surface of the reticle base plate 32 by the corner cube mirrors 35 and 37. The respective reflected light beams return via the same optical paths, and they are received by the respective double-path interferometers. Thus, the relative displacements of the respective corner cube mirrors 35 and 37 are measured with respect to the reference position (the reflective surface on the reticle base plate 32 as the reference position). Measured values obtained by the double-path interferometers are supplied to the stage control unit 38 shown in FIG. 1 to obtain an average value thereof, based on which the position of the

reticle stage RST in the Y-axis direction is measured. The information on the position in the Y-axis direction is used for calculation of the relative position between the reticle stage RST and the wafer stage WS1 or WS2 based on the measured value obtained by the interferometer disposed on the wafer side and having the length-measuring axis BI3Y. In addition, the information is used for synchronization control between the reticle and the wafer in the scanning direction (Y-axis direction) during the scanning exposure based thereon.

[0091]

On the other hand, a pair of corner cube mirrors 35 and 37 is installed on the other side (front side in the plane of the paper in FIG. 1) of the reticle stage RST in the Y-axis direction as the scanning direction. Interferometer beams, which are represented by length-measuring axes BI7Y and BI8Y in FIG. 2, are radiated from a pair of double-path interferometers (not shown in the figures) to the corner cube mirrors 35 and 37. The beams are returned to the reflective surface of the reticle base plate 32 by the corner cube mirrors 35 and 37. The respective reflected light beams return via the same optical paths, and they are received by the respective double-path interferometers. Thus, the relative displacements of the respective corner cube mirrors 35 and 37 are measured with respect to the reference position (the reflective surface on the reticle base plate 32 as the reference position). Measured values obtained by the double-path interferometers are supplied to the stage control unit 38 shown in FIG. 1 to obtain an average value thereof, based on which the position of the reticle stage RST in the Y-axis direction is measured. The information on the position in the Y-axis direction is used for calculation of the relative position between the reticle stage RST and the wafer stage WS1 or WS2 based on the measured value obtained by the interferometer disposed on the wafer side and having the length-

measuring axis BI3Y. In addition, the information is used for synchronization control between the reticle and the wafer in the scanning direction (Y-axis direction) during the scanning exposure based thereon.

[0092]

That is, in the present embodiment, the reticle interferometer system is constructed by the interferometer 36 and the pair of double-path interferometers represented by the length-measuring axes BI7Y and BI8Y.

[0093]

Next, an interferometer system for managing the positions of the wafer stages WST1 and WST2 will be described with reference to FIGS. 1 to 3.

[0094]

As shown in the drawings, the interferometer beam, which is represented by the first length-measuring axis BI1X from the interferometer 16 shown in FIG. 1, is radiated onto the surface of the wafer stage WS1 on one side in the X-axis direction along the first axis (X-axis) passing through the projection center of the projection optical system PL and the respective detection centers of the alignment systems 24a and 24b. Similarly, the interferometer beam, which is represented by the second length-measuring axis BI2X from the interferometer 18 shown in FIG. 1, is radiated onto the surface of the wafer stage WS2 on the other side in the X-axis direction along the first axis. Reflected light beams therefrom are received by the interferometers 16 and 18 so as to measure the relative displacements of the respective reflective surfaces from the reference position and measure the positions of the wafer stages WS1 and WS2 in the X-axis direction. In this case, as shown in FIG. 2, each of the interferometers 16 and 18 is a three-axis interferometer having three optical axes, making it possible to perform tilt measurement and θ measurement, in addition to the

measurement for the wafer stages WS1 and WS2 in the X-axis direction. Output values for the respective optical axes can be independently measured. In this case, θ stages (not shown in the figures) for performing θ rotation for the wafer stages WS1 and WS2, and Z-leveling stages (not shown in the figures) for performing minute driving and driving for inclination in the Z-axis direction are actually disposed under the reflective surfaces. Accordingly, all of the driving amounts concerning tilt control of the wafer stages can be monitored by the interferometers 16 and 18.

[0095]

The interferometer beams of the first length-measuring axis BI1X and the second length-measuring axis BI2X respectively strike the wafer stages WS1 and WS2 in all regions of the movement range of the wafer stages WS1 and WS2. Therefore, as for the X-axis direction, the positions of the wafer stages WS1 and WS2 are managed based on measured values obtained by the first length-measuring axis BI1X and the second length-measuring axis BI2X at any time, for example, during the exposure based on the use of the projection optical system PL and during the use of the alignment systems 24a and 24b.

[0096]

As shown in FIGS. 2 and 3, the projection exposure apparatus is provided with an interferometer having a third length-measuring axis BI3Y perpendicularly intersecting the first axis (X-axis) at the projection center of the projection optical system PL, and interferometers having length-measuring axes BI4Y and BI5Y, respectively, as fourth length-measuring axes perpendicularly intersecting the first axis (X-axis) at the respective detection centers of the alignment systems 24a and 24b. However, only the length-measuring axes are shown in the drawings.

[0097]

In the case of the present embodiment, the measured values obtained by the interferometer having the length-measuring axis BI3Y passing through the projection center of the projection optical system, i.e., the optical axis AX are used to measure the positions of the wafer stages WS1 and WS2 in the Y direction during the exposure based on the use of the projection optical system PL. The measured value obtained by the length-measuring axis BI4Y passing through the detection center of the alignment system 24a, i.e., the optical axis SX, is used to measure the position of the wafer stage WS1 in the Y direction during the use of the alignment system 24a. The measured value obtained by the length-measuring axis BI5Y passing through the detection center of the alignment system 24b, i.e., the optical axis SX is used to measure the position of the wafer stage WS2 in the Y direction during the use of the alignment system 24b.

[0098]

Therefore, the length-measuring axis of the interferometer in the Y direction is deviated from the reflective surfaces of the wafer stages WS1 and WS2 depending on the respective conditions of use. However, at least one of the length-measuring axes, i.e., the length-measuring axes BI1X and BI2X are not deviated from the reflective surfaces of the wafer stages WS1 and WS2, respectively. Accordingly, it is possible to reset the interferometer on the Y side at an appropriate position at which the optical axis of the interferometer to be used enters the reflective surface. The method for resetting the interferometer will be described in detail later.

[0099]

Each interferometer has the length-measuring axes BI3Y, BI4Y and BI5Y for Y measurement is a two-axis interferometer having two optical axes. They are capable of performing tilt measurement in addition to the measurement in the Y-axis

direction for the wafer stages WS1 and WS2. Output values concerning the respective optical axes can be measured independently.

[0100]

In the present embodiment, the interferometer system for managing the two-dimensional coordinate positions of the wafer stages WS1 and WS2 is constructed by five interferometers in total including the interferometers 16 and 18 and the three interferometers having the length-measuring axes BI3Y, BI4Y, and BI5Y.

[0101]

In addition, in the present embodiment, as described later, the exposure sequence is executed on one of the wafer stages WS1 and WS2, while the wafer exchange/wafer alignment sequence is executed on the other of the wafer stages WS1 and WS2. During this process, in order not to cause any interference between the two stages, the movement of the wafer stages WS1 and WS2 is managed by the stage control unit 38 in accordance with the command supplied from the main control unit 90 based on the output values obtained by the interferometers.

[0102]

Next, the illumination system will be described with reference to FIG. 1. As shown in FIG. 1, the illumination system includes, for example, an exposure light source 40, a shutter 42, a mirror 44, beam expanders 46 and 48, a first fly's eye lens 50, a lens 52, a vibration mirror 54, a lens 56, a second fly's eye lens 58, a lens 60, a fixed blind 62, a movable blind 64, and relay lenses 66 and 68.

[0103]

Each component of the illumination system will now be described together with its function.

[0104]

A laser beam is radiated from the light source unit 40 composed of a KrF excimer laser as a light source and a light-reducing system (for example, a light-reducing plate and an aperture diaphragm). The laser beam passes through the shutter 42, and is then polarized by the mirror 44, followed by being shaped to have an appropriate beam diameter by means of the beam expanders 46 and 48. The laser beam comes into the first fly's eye lens 50. The light beam coming into the first fly's eye lens 50 is divided into a plurality of light beams by elements of the fly's eye lens arranged two-dimensionally. Each light beam comes into the second fly's eye lens 58 again at different angles, by the aid of the lens 52, the vibration mirror 54, and the lens 56. The light beam outgoing from the second fly's eye lens 58 passes through the lens 60, and it arrives at the fixed blind 62 installed at a position conjugate to the reticle R. At this position, the light beam is defined to have a predetermined cross-sectional configuration, and it passes through the movable blind 64 disposed at a position slightly de-focused from the conjugate plane of the reticle R. The light beam passes through the relay lenses 66 and 68, and it is used as a uniform illumination light beam to illuminate a predetermined shape, i.e., a rectangular slit-shaped illumination area IA (see FIG. 2) on the reticle R defined by the fixed blind 62.

[0105]

Next, the control system will be described with reference to FIG. 1. The control system centers the main control unit 90, as control means, for controlling the entire apparatus, and it includes, for example, the exposure amount control unit 70 and the stage control unit 38 which are under the control of the main control unit 90.

[0106]

Description will now be made mainly for the operations of each constituent component of the control system as well as the operation of the projection exposure apparatus 10 according to the present embodiment during the exposure.

[0107]

Prior to the start of the synchronized scanning for the reticle R and the wafer (W1 or W2), the exposure amount control unit 70 instructs a shutter driver 72 to drive a shutter driving unit 74 so that the shutter 42 is opened.

[0108]

After that, the stage control unit 38 starts synchronized scanning (scan control) for the reticle R and the wafer (W1 or W2), i.e., the reticle stage RST and the wafer stage (WS1 or WS2) in accordance with the instruction given by the main control unit 90. The synchronized scanning is performed by controlling the linear motors for constructing the reticle driving unit 30 and the driving system for the wafer stages by the stage control unit 38 while monitoring the measured values obtained by using the length-measuring axis BI3Y and the length-measuring axis BI1X or BI2X of the interferometer system and the length-measuring axes BI7Y and BI8Y and the length-measuring axis BI6X of the reticle interferometer system.

[0109]

At the point of time at which both stages have been subjected to constant speed control within a predetermined allowable range, the exposure amount control unit 70 instructs a laser control unit 76 to start pulse light emission. Accordingly, the rectangular illumination area IA on the reticle R, on which a pattern is chromium vapor-deposited on its lower surface, is illuminated with the illumination light beam emitted from the illumination system. The image of the pattern in the illumination area is reduced 1/5-fold by the aid of the projection optical system PL, and is

projected for exposure onto the wafer (W1 or W2) applied with a photoresist on its surface. In this case, as will be clear from FIG. 2, the slit width of the illumination area IA in the scanning direction is narrow as compared with the pattern area on the reticle. The image of the entire surface of the pattern is successively formed on the shot area on the wafer by performing synchronized scanning for the reticle R and the wafer (W1 or W2) as described above.

[0110]

Simultaneously with the start of the pulse light emission described above, the exposure amount control unit 70 instructs a mirror driver 78 to vibrate the vibration mirror 54 so that the vibration of the vibration mirror is continuously performed until the pattern area on the reticle R completely passes over the illumination area IA (see FIG. 2), i.e., until the image on the entire surface of the pattern is formed on the shot area on the wafer. Thus, the interference fringe non-uniformity, which would otherwise be produced because of the two fly's eye lenses 50 and 58, is reduced.

[0111]

In addition, the movable blind 64 is driven and controlled by the blind control unit 39 in synchronization with the scanning for the reticle R and the wafer W so that the illumination light does not leak out to the outside of the shielding area on the reticle at the shot edge portion during the scanning exposure. The series of synchronized operations are managed by the stage control unit 38.

[0112]

Incidentally, in relation to the pulse light emission effected by the laser control unit 76 described above, it is necessary to emit light n times (n is a positive integer) during a period in which an arbitrary point on the wafer W1, W2 passes over the width (w) of the illumination field. Therefore, it is necessary to satisfy the following

expression (2) provided that the oscillation frequency is f, and the wafer scanning speed is V.

[0113]

$$f/n=V/w \quad \text{.........} \quad (2)$$

In addition, it is necessary to satisfy the following expression (3) provided that the radiation energy of one pulse radiated onto the wafer is P, and the resist sensitivity is E.

[0114]

$$nP=E \quad \text{.........} \quad (3)$$

As described above, the exposure amount control unit 70 is constructed such that computing operation is performed for all variable quantities of the radiation energy P and the oscillation frequency f to give a command to the laser control unit 76 so that the light-reducing system provided in the exposure light source 40 is controlled. Thus, the radiation energy P and the oscillation frequency f are varied, and the shutter driver 72 and the mirror driver 78 are controlled.

[0115]

In addition, for example, when correction is made for the movement start positions (synchronization positions) of the reticle stage and the wafer stage to be subjected to the synchronized scanning during the scanning exposure, the main control unit 90 instructs the stage control unit 38 which controls the movement of the stages to make correction for the stage position corresponding to the amount of correction.

[0116]

In addition, the projection exposure apparatus according to the present embodiment further includes a first transport system for performing wafer exchange

between itself and the wafer stage WS1, and a second transport system for performing wafer exchange between itself and the wafer stage WS2.

[0117]

As shown in FIG. 7, the first transport system performs wafer exchange as described later between itself and the wafer stage WS1 disposed at a wafer loading position on the left side. The first transport system includes a first wafer loader including, for example, a first loading guide 182 which extends in the Y-axis direction, first and second sliders 186 and 190 which are movable along the loading guide 182, a first unload arm 184 which is attached to the first slider 186, and a first load arm 188 which is attached to the second slider 190, and a first center-up 180 including three vertically movable members provided on the wafer stage WS1.

[0118]

The operation of wafer exchange by the first transport system will now be briefly described.

[0119]

As shown in FIG. 7, description will be made for a case in which the wafer W1' placed on the wafer stage WS1 disposed at the wafer loading position on the left side is exchanged with the wafer W1 transported by the first wafer loader.

[0120]

First, the main control unit 90 is operated to turn-off vacuum attraction by the wafer holder (not shown in the figures) on the wafer stage WS1 by the aid of a switch (not shown in the figures) so that attraction for the wafer W1' is de-energized.

[0121]

Next, the main control unit 90 is operated to drive and raise the center-up 180 by a predetermined amount with the aid of a center-up-driving system (not shown in

the figures). Accordingly, the wafer W1' is lifted up to a predetermined position. In this state, the main control unit 90 instructs a wafer loader control unit (not shown in the figures) to move the first unload arm 184. Accordingly, the first slider 186 is driven and controlled by the wafer loader control unit. The first unload arm 184 is moved to a position over the wafer stage WS1 along the loading guide 182, and it is located at the position just under the wafer W1'.

[0122]

In this state, the main control unit 90 is operated to downwardly drive the center-up 180 to a predetermined position. During the downward movement of the center-up 180, the wafer W1' is transmitted to and received by the first unload arm 184. Therefore, the main control unit 90 instructs the wafer loader control unit to start vacuum attraction for the first unload arm 184. Accordingly, the wafer W1' is drawn and held by the first unload arm 184.

[0123]

Next, the main control unit 90 instructs the wafer loader control unit to start retraction of the first unload arm 184 and movement of the first load arm 188. Accordingly, the first unload arm 184 starts movement in the -Y direction in FIG. 7 integrally with the first slider 186, simultaneously with which the second slider 190 starts movement in the +Y direction integrally with the first load arm 188 which holds the wafer W1. When the first load arm 188 arrives at a position over the wafer stage WS1, the wafer loader control unit stops movement of the second slider 190, and the vacuum attraction for the first load arm 188 is de-energized.

[0124]

In this state, the main control unit 90 is operated to upwardly drive the center-up 180. Thus, the underlying center-up 180 is allowed to lift up the wafer W1. Next,

the main control unit 90 instructs the wafer loader control unit to retract the load arm. Accordingly, the second slider 190 starts movement in the -Y direction integrally with the first load arm 188, and the first load arm 188 is retracted. As retraction of the first load arm 188 is started, the main control unit 90 starts downward driving for the center-up 180, simultaneously. Thus, the wafer W1 is placed on the wafer holder on the wafer stage WS1, and vacuum attraction effected by the wafer holder is turned on. Accordingly, a series of sequence for wafer exchange is completed.

[0125]

Similarly, as shown in FIG. 8, a second transport system performs wafer exchange in the same manner as described above between itself and the wafer stage WS2 disposed at a wafer loading position on the right side. The second transport system includes a second wafer loader including, for example, a second loading guide 192 which extends in the Y-axis direction, third and fourth sliders 196, 200 which are movable along the second loading guide 192, a second unload arm 194 which is attached to the third slider 196, and a second load arm 198 which is attached to the fourth slider 200, and an second center-up (not shown in the figures) provided on the wafer stage WS2.

[0126]

Next, with reference to FIGS. 7 and 8, description will be made for the parallel processing based on the use of the two wafer stages, which is the feature of the present embodiment.

[0127]

FIG. 7 shows a plan view showing a state in which the wafer is exchanged between the wafer stage WS1 and the first transport system as described above at the left loading position during the period in which the exposure operation is performed

for the wafer W2 on the wafer stage WS2 by the aid of the projection optical system PL. In this case, after performing the wafer exchange, the alignment operation is continuously performed on the wafer stage WS1 as described later. In FIG. 7, the position of the wafer stage WS2 during the exposure operation is controlled based on measured values obtained by using the length-measuring axes BI2X and BI3Y of the interferometer system. The position of the wafer stage WS1, on which the wafer exchange and the alignment operation are performed, is controlled based on measured values obtained by using the length-measuring axes BI1X and BI4Y of the interferometer system.

[0128]

At the left loading position shown in FIG. 7, the arrangement is made such that the reference mark on the fiducial mark plate FM1 of the wafer stage WS1 is disposed just under the alignment system 24a (See FIG. 9(A)). Accordingly, the main control unit 90 resets the interferometer having the length-measuring axis BI4Y of the interferometer system prior to the measurement of the reference mark MK2 on the reference mark plate FM1, performed by the alignment system 24a.

[0129]

FIG. 9(B) shows an example and the shape of the reference mark MK2 and a state of image pick-up for detecting the reference mark MK2 by the sensor based on the FIA system of the alignment system 24a. In FIG. 9(B), a symbol Sx indicates an image pick-up range for CCD, and a cross-shaped mark indicated by a symbol M indicates an index included in the sensor of the FIA system. In this drawing, only the image pick-up range in the X-axis direction is depicted. However, in practice, it is a matter of course that a similar image pick-up procedure is also executed in the Y direction.

[0130]

FIG. 9(C) shows a waveform signal obtained by an image processing system included in the alignment control unit 80 when the image of the mark MK2 shown in FIG. 9(B) is picked up by the sensor of the FIA system. The alignment control unit 80 analyzes the waveform signal to detect the position of the mark MK2 based on the index center. The main control unit 90 calculates the coordinate position of the mark MK2 on the fiducial mark plate FM1 in a coordinate system (hereinafter referred to as "first stage coordinate system", where appropriate) based on the use of the length-measuring axes BI1X and BI4Y, based on the position of the mark MK2 and the result of measurement effected by the length-measuring axes BI1X and BI4Y.

[0131]

Search alignment is performed continuously after performing the wafer exchange and the reset for the interferometer described above. The search alignment, which is performed after the wafer exchange, is pre-alignment performed again on the wafer stage WS1, because the positional error is large if pre-alignment is performed during only the transport of the wafer W1. Specifically, positions of three search alignment marks (not shown), which are formed on the wafer W1 placed on the stage WS1, are measured by using, for example, the sensor of the LSA system of the alignment system 24a. Positional adjustment is performed for the wafer W1 in the X, Y, □ directions based on obtained results of the measurement. During the search alignment, the operations of each component is controlled by the main control unit 90.

[0132]

After completion of the search alignment, fine alignment is performed to determine the arrangement of the shot areas on the wafer W1 by using EGA in this embodiment. Specifically, the positions of the alignment marks of predetermined

sample shots on the wafer W1 are measured by using, for example, the sensor of the FIA system of the alignment system 24a while successively moving the wafer stage WS1 based on designed shot array data (data on alignment mark positions), while managing the position of the wafer stage WS1 by the interferometer system (length-measuring axes BI1X and BI4Y). All shot array data are computed in accordance with statistical calculation based on the least square method based on obtained results of the measurement and the designed coordinate data on the shot array. In this way, the coordinate positions of the shots on the first stage coordinate system described above are calculated. During the process of EGA, the operations of the respective components are controlled by the main control unit 90. The computing operation described above is performed by the main control unit 90.

[0133]

The main control unit 90 calculates the relative positional relationship for the shots with respect to the mark MK2 by subtracting the coordinate position of the reference mark MK2 from the coordinate positions of the shots.

[0134]

As described above, in the case of the present embodiment, during the measurement performed by the alignment system 24a, the position of the alignment mark is measured while executing autofocus/autoleveling based on the measurement and control effected by the AF/AL system 132 (see FIG. 4) in the same manner as performed during the exposure. Thus, it is possible to avoid occurrence of any offset (error) which would be otherwise caused between the process of alignment and the process of exposure, due to the posture of the stage.

[0135]

During the period in which the wafer exchange and the alignment operation are performed for the wafer stage WS1 as described above, double exposure is performed for the wafer stage WS2 in a continuous manner in accordance with the step-and-scan method while changing the exposure condition by using two reticles R1 and R2 as shown in FIG. 12.

[0136]

Specifically, the relative positional relationship for the shots with respect to the mark MK2 has been previously calculated in the same manner as performed for the wafer W1. Based on obtained results of the calculation and results of detection of relative positions of the marks MK1 and MK3 on the fiducial mark plate FM1 and projected images on the wafer surface, of the marks RMK1 and RMK3 on the reticle corresponding thereto based on the use of the reticle alignment microscopes 144 and 142 (this process will be described in detail later), the shot areas on the wafer W2 are successively positioned under the optical axis of the projection optical system PL. In addition, the reticle stage RST and the wafer stage WS2 are subjected to synchronized scanning in the scanning direction every time when each of the shot areas is subjected to exposure. Thus, the scanning exposure is carried out.

[0137]

The exposure for all of the shot areas on the wafer W2 as described above is also continuously performed after the reticle exchange. Specifically, the exposure procedure of the double exposure proceeds in the following order as shown in FIG. 13(A). That is, the shot areas on the wafer W1 are successively subjected to a scanning exposure from A1 to A12 by using the reticle R2 (pattern A). After that, the reticle stage RST is moved in a predetermined amount in the scanning direction by using the driving system 30 to set the reticle R1 (pattern B) at the exposure position.

Thereafter, scanning exposure is performed in an order from B1 to B12 as shown in FIG. 13(B). In this procedure, the exposure condition (AF/AL, exposure amount) and the transmittance differ between the reticle R2 and the reticle R1. Therefore, it is necessary that the respective conditions are measured during the reticle alignment, and the conditions are changed depending on obtained results.

[0138]

The operations of the respective components during the double exposure for the wafer W2 are also controlled by the main control unit 90.

[0139]

The exposure sequence and the wafer exchange/alignment sequence are concurrently performed in parallel on the two wafer stages WS1 and WS2 shown in FIG. 7 described above. In this process, the wafer stage of the two wafer stages, on which the operation has been completed, is in a waiting state. At the point of time at which the operations for both wafer stages have been completed, the wafer stages WS1 and WS2 are controlled and moved to the positions shown in FIG. 8. The wafer W2 on the wafer stage WS2, for which the exposure sequence has been completed, is subjected to wafer exchange at the right loading position. The wafer W1 on the wafer stage WS1, for which the alignment sequence has been completed, is subjected to the exposure sequence under the projection optical system PL.

[0140]

At the right loading position shown in FIG. 8, the reference mark MK2 on the fiducial mark plate FM2 is positioned under the alignment system 24b in the same manner as operated for the left loading position. The wafer exchange operation and the alignment sequence are executed as described above. Of course, the reset operation for the interferometer having the length-measuring axis BI5Y of the

interferometer system has been executed prior to the detection of the mark MK2 on the fiducial mark plate FM2 effected by the alignment system 24b.

[0141]

Next, description will be made for the reset operation for the interferometer, performed by the main control unit 90 during the change from the state shown in FIG. 7 to the state shown in FIG. 8.

[0142]

After the alignment is performed at the left loading position, the wafer stage WS1 is moved to the position at which the reference mark (See FIG. 10(A)) on the fiducial plate FM1 comes just under the center (projection center) of the optical axis AX of the projection optical system PL shown in FIG. 8. During this movement, the interferometer beam for the length-measuring axis BI4Y does not come into the reflective surface 21 of the wafer stage WS1. Therefore, it is difficult to move the wafer stage WS1 to the position shown in FIG. 8 immediately after completion of the alignment. For this reason, in the present embodiment, the following artifice is conceived.

[0143]

That is, as described above, in the present embodiment, it is set such that the fiducial mark plate FM1 comes just under the alignment system 24a when the wafer stage WS1 is disposed at the left loading position. The interferometer having the length-measuring axis BI4Y is reset at this position. Therefore, the wafer stage WS1 is once returned to this position. The wafer stage WS1 is moved from the position rightwardly in the X-axis direction by a distance BL while monitoring the measured value obtained by the interferometer 16 having the length-measuring axis BI1X for which the interferometer beam is not intercepted, based on the previously known

distance (conveniently referred to as "BL") between the detection center of the alignment system 24a and the center (projection center) of the optical axis of the projection optical system PL. Accordingly, the wafer stage WS1 is moved to the position shown in FIG. 8.

[0144]

As shown in FIG. 10(A), the main control unit 90 is operated to detect the relative positions of the marks MK1 and MK3 on the fiducial mark plate FM1 and projected images on the wafer surface, of the marks RMK1 and RMK3 on the reticle corresponding thereto, based on the use of the exposure light beam by the reticle alignment microscopes 144 and 142.

[0145]

FIG. 10(B) shows the projected image on the wafer surface, of the mark RMK (RMK1, RMK2) on the reticle R, and FIG. 10(C) shows the mark MK (MK1, MK3) on the fiducial mark plate. In addition, FIG. 10(D) shows a state of image pick-up for simultaneously detecting the projected image on the wafer surface, of the mark RMK (RMK1, RMK2) on the reticle R and the mark MK (MK1, MK3) on the fiducial mark plate, by the reticle alignment microscope 144 and 142, in the state shown in FIG. 10(A). In FIG. 10(D), a symbol SRx indicates an image pick-up range for CCD which constructs the reticle alignment microscope. FIG. 10(E) shows a waveform signal obtained by processing the image picked up as described above by the aid of an unillustrated image processing system.

[0146]

The main control unit 90 resets the interferometer having the length-measuring axis BI3Y prior to the pick-up of the waveform signal. The reset operation can be

executed at the point of time at which the length-measuring axis to be used next is available to radiate the side surface of the wafer stage.

[0147]

Accordingly, the coordinate positions of the marks MK1 and MK3 on the fiducial mark plate FM1, and the coordinate positions of the marks RMK on the reticle R projected on the wafer surface are detected in the coordinate system (second stage coordinate system) based on the use of the length-measuring axes BI1X, BI3Y. Based on the difference between both coordinate positions, the relative positional relationship between the exposure position (the projection center of the projection optical system PL) and the coordinate positions of the marks MK1 and MK3 on the fiducial mark plate FM1 is determined.

[0148]

The main control unit 90 calculates the relative positional relationship between the exposure position and each of the shots in accordance with the previously determined relative positional relationship of each of the shots with respect to the mark MK2 on the fiducial mark plate FM1, and the relative relationship between the exposure position and the coordinate positions of the marks MK1 and MK3 on the fiducial mark plate FM1. Depending on an obtained result, the shots on the wafer W1 are subjected to the exposure as shown in FIG. 11.

[0149]

The reason why the highly accurate alignment can be performed even when the reset operation is performed for the interferometer as described above is as follows. That is, the spacing distance between the reference mark and the imaginary position calculated in accordance with the measurement of the wafer mark is calculated by the same sensor by measuring the reference mark on the fiducial mark

plate FM1 by means of the alignment system 24a, and then measuring the alignment mark on each of the shot areas on the wafer W1. At this point of time, the relative distance between the reference mark and the position to be subjected to exposure is determined. Accordingly, if the correspondence between the exposure position and the reference mark position is established before the exposure by the reticle alignment microscopes 142 and 144, it is possible to perform the highly accurate exposure operation by adding the relative distance to the obtained value, even when the interferometer beam for the interferometer in the Y-axis direction is intercepted during the movement of the wafer stage, and the reset is performed again.

[0150]

The reference marks MK1 to MK3 always exist on the same fiducial plate. Therefore, if the drawing error is determined beforehand, only the management for the offset is required, and there is no variable factor. There is a possibility that the RMK1 and RMK2 also have an offset due to a drawing error of the reticle. However, such a state may be also dealt with by means of only the offset management, if the drawing error is reduced by a plurality of marks during the reticle alignment, or if the drawing error of the reticle mark is measured beforehand, as disclosed, for example, in Japanese Unexamined Patent Application Publication No. 5-67271.

[0151]

When the length-measuring axis BI4Y is not intercepted during the period of movement of the wafer stage WS1 from the alignment completion position to the position shown in FIG. 8, it is a matter of course that the wafer stage WS1 may be linearly moved to the position shown in FIG. 8 immediately after completion of the alignment while monitoring the measured values obtained by using the length-measuring axes BI1X and BI4Y. In this case, it is preferable to perform the reset

operation for the interferometer at or after the point of time at which the length-measuring axis BI3Y passing through the optical axis AX of the projection optical system PL overlaps the reflective surface 21 of the wafer stage WS1 perpendicular to the Y-axis, and before the detection of the relative positions of the marks MK1 and MK3 on the fiducial mark plate FM1 and the projected images on the wafer, of the marks RMK1 and RMK3 on the reticle corresponding thereto based on the use of the reticle alignment microscopes 144 and 142.

[0152]

The wafer stage WS2 may be moved from the exposure completion position to the right loading position shown in FIG. 8 in the same manner as described above to perform the reset operation for the interferometer having the length-measuring axis BI5Y.

[0153]

In addition, FIG. 14 shows an example of the timing of the exposure sequence for successively exposing the respective shot areas on the wafer W1 held on the wafer stage WS1. FIG. 15 shows the timing of the alignment sequence for the wafer W2 held on the wafer stage WS2, performed concurrently in parallel thereto. In the present embodiment, the exposure sequence and the wafer exchange/alignment sequence are concurrently performed in parallel to one another for the wafers W1 and W2 held on the wafer stages while independently moving the two wafer stages WS1 and WS2 in the two-dimensional directions so that the throughput is improved.

[0154]

However, when the two operations are dealt with concurrently in parallel to one another by using the two wafer stages, the operation performed on one of the stages affects, as a disturbance factor, the operation performed on the other wafer

stage in some cases. On the contrary, some of the operations performed on one of the wafer stages do not affect the operations performed on the other wafer stage. Thus, in the present embodiment, the operations performed concurrently in parallel are divided into the operations which correspond to the disturbance factor, and the operations which do not correspond to the disturbance factor. In addition, the timings of each operation is adjusted so that the operations which correspond to the disturbance factor, or the operations which do not correspond to the disturbance factor are performed simultaneously.

[0155]

For example, during the scanning exposure, the synchronized scanning for the wafer W1 and the reticle R is performed at constant speed, in which no disturbance factor is included. In addition, it is necessary to exclude any external disturbance factor as much as possible. Therefore, during the scanning exposure performed on one of the wafer stages WS1, the timing is adjusted to give a stationary state in the alignment sequence for the wafer W2 on the other wafer stage WS2. That is, the measurement of the mark in the alignment sequence is performed in a state in which the wafer stage WS2 is allowed to stand still at the mark position. Therefore, the measurement of the mark is not the disturbance factor for the scanning exposure. Thus, it is possible to perform the measurement of the mark concurrently with the scanning exposure in parallel. In this context, with reference to FIGS. 14 and 15, it is understood that the scanning exposure for the wafer W1 indicated by the operation numbers of "1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23" shown in FIG. 15 is performed in a mutually synchronized manner with respect to the mark measurement operation effected at the respective alignment mark positions for the wafer W2 indicated by the operation numbers of "1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23" shown in FIG. 16. On

the other hand, in the case of the alignment sequence, the constant speed movement is also performed during the scanning exposure. Therefore, no disturbance occurs, and it is possible to perform the measurement highly accurately.

[0156]

The same state as that described above is also considered for the wafer exchange. Particularly, for example, any vibration, which is generated when the wafer is transmitted from the load arm to the center-up, may serve as a disturbance factor. Therefore, the wafer may be transmitted in conformity with acceleration or deceleration (which may serve as a disturbance factor) before or after the synchronized scanning is performed at a constant speed.

[0157]

The timing adjustment described above is performed by the main control unit 90.

[0158]

As described above, according to the projection exposure apparatus 10 of the present embodiment, the two wafer stages WS1 and WS2 are provided for independently holding the two wafers. The two wafer stages are independently moved in the XYZ directions, wherein the wafer exchange operation and the alignment operation are executed for one of the wafer stages, during which the exposure operation is executed for the other wafer stage. The operations of the wafer stages are switched to each other changed at the point of time at which both operations are completed. Accordingly, it is possible to greatly improve the throughput.

[0159]

In addition, during the change of the operations described above, the interferometer having the length-measuring axis to be used for the operation after the change is reset, simultaneously with which the measurement sequence is also performed for the fiducial mark plate disposed on the wafer stage. Therefore, no special inconvenience occurs even when the length-measuring axis of the interferometer system is deviated from the reflective surface of the wafer stage (or from the movement mirror, if the movement mirror is separately provided). Thus, it is possible to shorten the reflective surface of the wafer stage (or the movement mirror, if the movement mirror is separately provided). Accordingly, it is possible to easily realize miniaturization of the wafer stage. Specifically, the length of one side of the wafer stage can be decreased to have a size of a degree which is slightly larger than the diameter of the wafer. Thus, it is possible to easily incorporate, into the apparatus, the two wafer stages which are independently movable. In addition, it is possible to improve the positioning performance for the wafer stages.

[0160]

As for the wafer stage for which the exposure operation is performed, the mark on the fiducial mark plate is measured simultaneously with the reset for the length-measuring interferometer by the reticle alignment microscope 142, 144 (alignment sensor based on the use of the exposure light beam) by the aid of the projection optical system PL. As for the wafer stage for which the wafer exchange/alignment operation is performed, the mark on the fiducial mark plate is measured simultaneously with the reset for the length-measuring interferometer by the alignment system 24a or 24b (off-axis alignment sensor). Therefore, it is also possible to change the length-measuring axis of the interferometer for managing the position of the wafer stage during the alignment effected by each of the alignment

systems and during the exposure by the projection optical system. In this process, the following procedure is adopted. That is, (1) when the mark on the fiducial mark plate is measured by the alignment system 24a or 24b, the coordinate position of the mark is measured on the first stage coordinate system. (2) The alignment mark of a sample shot on the wafer is thereafter detected to determine the array coordinate (coordinate position for the exposure) of each shot is determined on the first stage coordinate system in accordance with the EGA operation. (3) The relative positional relationship between the mark on the fiducial mark plate and the coordinate position for the exposure of each shot is determined from the results obtained in (1) and (2) described above. (4) The relative positional relationship between the mark on the fiducial mark plate and the coordinate position of those projected from the reticle is detected before the exposure on the second stage coordinate system by the aid of the projection optical system PL by the reticle alignment microscope 142, 144. (5) The exposure is performed for each shot by using (3) and (4) described above. Accordingly, the exposure can be performed highly accurately even in the case of the change of the length-measuring axis of the interferometer for managing the position of the wafer stage. As a result, it is possible to perform the alignment for the wafer without performing the baseline measurement which has been hitherto carried out to measure the spacing distance between the projection center of the projection optical system and the detection center of the alignment system. It is also unnecessary to mount a large fiducial mark plate as described in Japanese Unexamined Patent Application Publication No. 7-176468.

[0161]

In addition, according to the embodiment described above, there are provided at least two alignment systems for detecting the mark, the two alignment systems

being disposed with the projection optical system PL interposed therebetween. Accordingly, the alignment operation and the exposure operation, which are performed by alternately using the alignment systems, can be concurrently dealt with in parallel to one another by alternately moving the two wafer stages.

[0162]

In addition, according to the embodiment described above, the wafer loader for exchanging the wafer is arranged in the vicinity of the alignment system, particularly to perform the operation at the alignment positions. Accordingly, the change from the wafer exchange to the alignment sequence is smoothly performed. Thus, it is possible to obtain a higher throughput.

[0163]

In addition, according to the embodiment described above, the influence causing deterioration of throughput disappears almost completely, even when the off-axis alignment system is installed at a position greatly separated from the projection optical system PL, because the high throughput is obtained as described above. Therefore, it is possible to design and install a straight cylinder type optical system having a high NA (numerical aperture) and having a small aberration.

[0164]

In addition, according to the embodiment described above, each of the optical systems has the interferometer beam radiated from the interferometer for measuring the approximate center of each of the optical axes of the two alignment systems and the projection optical system PL. Accordingly, the positions of the two wafer stages can be accurately measured in a state free from any Abbe error at any time of the alignment and the pattern exposure by the aid of the projection optical system. Thus, it is possible to independently move the two wafer stages.

[0165]

In addition, the length-measuring axes BI1X and BI2X, which are provided toward the projection center of the projection optical system PL from both sides in the direction (X-axis direction in this embodiment) along which the two wafer stages WS1 and WS2 are aligned, are aimed the wafer stages WS1 and WS2 so that the positions of the respective stages in the X-axis direction are measured. Therefore, it is possible to move and control the two wafer stages so that they exert no interference with each other.

[0166]

In addition, according to the embodiment described above, the double exposure is performed by using a plurality of reticles R. Accordingly, an effect of increasing the resolution and improving DOF (depth of focus) is obtained. However, in the double exposure method, it is necessary to repeat the exposure step at least twice. For this reason, there is an inconvenience in that the exposure time is prolonged, and the throughput is greatly decreased. However, the use of the projection exposure apparatus according to the present embodiment makes it possible to greatly improve the throughput. Therefore, it is possible to obtain the effect of increasing the resolution and improving DOF without decreasing the throughput.

[0167]

For example, it is assumed that the respective processing times of T1 (wafer exchange time), T2 (search alignment time), T3 (fine alignment time), and T4 (exposure time for one exposure) for an 8-inch wafer are T1: 9 seconds, T2: 9 seconds, T3: 12 seconds, and T4: 28 seconds. When the double exposure is performed in accordance with the conventional technique in which a series of exposure processes are performed by using one wafer stage, there is given a

throughput THOR=3600/(T1+T2+T3+T4□2)=3600/(30+28□2)=41 [sheets/hour]. Therefore, the throughput is lowered to be up to 66% as compared with a throughput (THOR=3600/(T1+T2+T3+T4)=3600/58=62 [sheets/hour]) obtained by a conventional apparatus in which the single exposure method is carried out by using one wafer stage. On the contrary, when the double exposure is performed by the projection exposure apparatus according to the present embodiment while concurrently processing T1, T2, T3, T4 in parallel to one another, there is given a throughput THOR=3600/(28+28)=64 [sheets/hour], because the exposure time is large. Therefore, the throughput can be improved greatly while maintaining the effect of increasing the resolution and improving DOF. In addition, the number of points for EGA can be increased as the exposure time increases. Thus, the alignment accuracy is improved.

[0168]

Second Embodiment

Next, the second embodiment of the present invention will be described with reference to FIGS. 16 and 17. In this case, constituent components which are the same as or equivalent to those of the first embodiment described above are designated by the same reference numerals and description thereof will be simplified or omitted.

[0169]

As shown in FIG. 16, a projection exposure apparatus according to the second embodiment is characterized in that since the length of one side of the wafer stage WS1 (the length of one side of WS2 is the same) is longer than the mutual distance BL between the length-measuring axes BI4Y and BI3Y (the mutual distance between the length-measuring axes BI5Y and BI3Y is the same), the length-measuring beam BI4Y (or BI5Y) is not deviated from the reflective surface of the stage during the

movement of the wafer stage WS1 (or WS2) from the completion position of the alignment sequence to the start position of the exposure sequence. Accordingly, the projection exposure apparatus according to the second embodiment is different from the projection exposure apparatus according to the first embodiment described above, in that the reference mark on the fiducial mark plate can be measured after the reset of the interferometer as described later. Other features are constructed in the same manner as the projection exposure apparatus 10 according to the first embodiment described above.

[0170]

FIG. 16 shows a state in which the interferometer having the length-measuring axis BI3Y is reset after completion of the alignment for the wafer W1 on the wafer stage WS1.

[0171]

As will be clear from FIG. 16, the interferometers having the length-measuring axes BI1X, BI4X for managing the position of the wafer stage WS1 have their interferometer beams which are not deviated from the reflective surface formed on one end surface of the wafer stage WS1 in the Y-axis direction, after the fine alignment operation (effected by EGA described above) for the wafer W1 by the aid of the alignment system 24a. Accordingly, the main control unit 90 is operated to move the wafer stage WS1 from the alignment completion position to the position shown in FIG. 16 at which the fiducial mark plate FM1 is located under the projection lens PL, while monitoring measured values obtained by the interferometers having the length-measuring axes BI1X and BI4Y. During this process, the interferometer beam of the length-measuring axis BI3Y is reflected by the reflective surface of the wafer

stage WS1 immediately before the fiducial mark plate FM1 is positioned just under the projection lens PL.

[0172]

In this case, the position of the wafer stage WS1 is controlled based on the measured values obtained by the interferometers having the length-measuring axes BI1X and BI4Y. Therefore, unlike the first embodiment described above, the main control unit 90 can accurately manage the position of the wafer stage WS1. At this point in time (i.e., immediately before the fiducial mark plate FM1 is positioned just under the projection lens PL), the interferometer having the length-measuring axis BI3Y is reset. After completion of the reset, the position of the wafer stage WS1 is controlled based on measured values obtained by the interferometers having the length-measuring axes BI1X and BI3Y (the coordinate system is changed from the first stage coordinate system to the second stage coordinate system).

[0173]

After that, the main control unit 90 is operated so that the wafer stage WS1 is positioned at the position shown in FIG. 16 to perform the detection of the relative position between the marks RMK1 and RMK3 on the fiducial mark plate FM1 and the projected images on the wafer surface, of the marks RMK1 and RMK3 on the reticle corresponding thereto, i.e., the detection of the relative positional relationship between the marks MK1 and MK3 and the exposure position (projection center of the projection optical system PL) by using the exposure light beam based on the use of the reticle microscopes 142 and 144, in the same manner as performed in the first embodiment described above. After that, the main control unit 90 finally calculates the relative positional relationship between the exposure position and each shot in accordance with the relative positional relationship of each shot with respect to the

mark MK2 on the fiducial mark plate FM1 previously determined and the relative positional relationship between the exposure position and the coordinate position of the mark MK1, MK3 on the fiducial mark plate FM1. Thus, the exposure (double exposure as described above) is performed in accordance with an obtained result (see FIG. 11).

[0174]

During the exposure, the length-measuring axis BI4Y is deviated from the reflective surface depending on the exposure position, and the measurement therewith becomes impossible. However, no inconvenience occurs because the length-measuring axis has been already changed for the control of the position of the wafer stage WS1.

[0175]

The operation of the exposure sequence is performed on the side of the one wafer stage WS1, during which the other wafer stage WS2 is subjected to the positional control based on the measured values obtained by the interferometers having the length-measuring axes BI2X and BI5Y, in which the W exchange sequence and the wafer alignment sequence are executed. In this process, the double exposure is performed on the side of the wafer stage WS1 as described above. Therefore, the operation of the wafer exchange sequence and the wafer alignment sequence performed on the side of the wafer stage WS2 are completed earlier, and then the wafer stage WS2 is in a waiting state.

[0176]

At the time at which the exposure for all areas of the wafer W1 is completed, the main control unit 90 is operated to move the wafer stage WS1 to the position at which the interferometer beam concerning the length-measuring axis BI4Y is

reflected by the reflective surface of the wafer stage WS1 while monitoring measured values obtained by the interferometers concerning the length-measuring axes BI1X and BI3Y so that the interferometer having the length-measuring axis BI4Y is reset. After completion of the reset operation, the main control unit 90 is operated to change the length-measuring axes for controlling the wafer stage WS1 into the length-measuring axes BI1X and BI4Y again so that the wafer stage WS1 is moved to the loading position.

[0177]

During the movement, the interferometer beam concerning the length-measuring axis BI3Y is at this point deviated from the reflective surface, and it falls into an immeasurable state. However, no inconvenience is caused because the length-measuring axis has been changed to control the position of the wafer stage WS1.

[0178]

The main control unit 90 is operated to start movement of the wafer stage WS2 so that the fiducial mark plate FM2 for the wafer stage WS2 is positioned under the projection optical system PL, concurrently with the movement of the wafer stage WS1 to the loading position. During the movement, the reset of the interferometer having the length-measuring axis BI3Y is executed in the same manner as described above. After that, the reticle microscopes 142 and 144 are used to perform the detection of the relative positions of the marks MK1 and MK3 on the fiducial mark plate FM2 and the projected images on the wafer surface, of the marks RMK1 and RMK3 on the reticle corresponding thereto, i.e., the detection of the relative positional relationship between the marks RMK1 and RMK3 and the exposure position (projection center of the projection optical system PL), in the same manner as described above. Subsequently, the main control unit 90 finally calculates the relative

positional relationship between the exposure position and each shot in accordance with the relative positional relationship of each shot with respect to the mark MK2 on the fiducial mark plate FM2 previously determined and the relative positional relationship between the exposure position and the coordinate position of the mark MK1 and MK3 on the fiducial mark plate FM2. Thus, the exposure (double exposure as described above) is started in accordance with an obtained result.

[0179]

FIG. 17 shows a state in which the wafer stage WS1 is moved to the loading position as described above, and the operation of the exposure sequence is performed on the side of the wafer stage WS2.

[0180]

At the loading position, the mark MK2 on the fiducial mark plate FM1 is positioned under the alignment system 24a in the same manner as described in the first embodiment. The main control unit 90 is operated to detect the coordinate position of the mark MK2 on the first stage coordinate system (BI1X, BI4Y) simultaneously with completion of the wafer exchange in the same manner as described in the first embodiment. Subsequently, the EGA measurement is carried out for the mark on the wafer W1 to calculate the coordinate position of each shot in the same coordinate system. That is, the relative positional relationship of each shot with respect to the mark MK2 is calculated by subtracting the coordinate position of the mark MK2 on the fiducial mark plate FM1 from the coordinate position of each shot. The EGA operation is completed at this point in time, and the system waits for completion of the exposure for the wafer W2 on the wafer stage WS2 to make a change again to the state shown in FIG. 16.

[0181]

According to the projection exposure apparatus of the present second embodiment described above, it is possible to obtain effects equivalent to those obtained in the first embodiment described above. In addition to this, the reflection is allowed to occur simultaneously on the reflective surface of the wafer stage for the length-measuring axes used before and after the change, respectively during the movement of the stage when the change is made to the operation of the exposure sequence after completion of the operation of the alignment sequence. In addition, the reflection is allowed to occur simultaneously on the reflective surface of the wafer stage for the length-measuring axes used before and after the change, during the movement of the stage when the change is made to the operation of the wafer exchange/alignment sequence after completion of the operation of the exposure sequence. Accordingly, it is possible that the mark on the fiducial mark plate is measured after the reset of the length-measuring interferometer by using the exposure light beam alignment sensor (reticle alignment microscope 142, 144) by the aid of the projection optical system PL, the reset for the length-measuring interferometer is executed prior to the wafer exchange, and the mark on the fiducial mark plate is measured after completion of the wafer exchange by using the off-axis alignment sensor (alignment system 24a and 24b). Therefore, the interferometer to be used for the stage control can be changed to the interferometer having the length-measuring axis to be used for the operation after the change, during the change from the alignment operation based on the use of each alignment system to the exposure operation based on the use of the projection optical system PL, and during the change from the exposure operation based on the use of the projection optical system PL to the wafer exchange operation. Accordingly, it is possible to further improve the throughput, as compared with the case of the first embodiment in which the length-

measuring axis is changed simultaneously with the measurement of the mark on the fiducial mark plate.

[0182]

In the first and second embodiments described above, description has been made of the case in which the present invention is applied to the apparatus for exposing the wafer based on the use of the double exposure method. However, such description has been made because of the following reason. That is, as described above, when the exposure is performed twice with the two reticles (double exposure) on the side of one of the wafer stages, during which the wafer exchange and the wafer alignment are concurrently carried out in parallel on the side of the other wafer stage which is independently movable, by the apparatus according to the present invention, a particularly large effect can be obtained in that the high throughput can be obtained as compared with the conventional single exposure, and the resolving power can be greatly improved. However, the range of application of the present invention is not limited thereto. The present invention can be preferably applied when the exposure is performed in accordance with the single exposure method. For example, it is assumed that the respective processing times (T1 to T4) for an 8-inch wafer are the same as those described above. When the exposure process is performed in accordance with the single exposure method by using the two wafer stages as in the present invention, if T1, T2, T3 are dealt with as one group (30 seconds in total), and the concurrent process is performed for T4 (28 seconds), then there is given a throughput THOR=3600/30=120 [sheets/hour]. Thus, it is possible to obtain the high throughput which is approximately twice the throughput (THOR=62 [sheets/hour]) of the conventional apparatus in which the single exposure is carried out by using one wafer stage.

[0183]

In the embodiment described above, description has been made of the case in which the scanning exposure is performed in accordance with the step-and-scan method. However, the present invention is not limited thereto. It is a matter of course that the present invention can be equivalently applied to a case in which the stationary exposure is performed in accordance with the step-and-repeat method, as well as those based on the use of the electron-beam exposure apparatus (EB exposure apparatus) and the X-ray exposure apparatus, and a process of the stitching exposure in which a chip is combined with another chip.

[0184]

Effects of the Invention

As described above, according to the inventions described in Claims 1 to 4 and 6 to 11, an excellent effect, which has not been obtained in the conventional technique, is obtained in that it is possible to improve the throughput and achieve miniaturization and weight-reduction of the substrate stage.

[0185]

In addition, according to the invention described in Claim 5, a projection exposure method capable of improving the throughput and achieving miniaturization and weight-reduction of the stage is provided.

Brief Description of the Drawings

FIG. 1

FIG. 1 is a diagram showing a schematic arrangement of the projection exposure apparatus according to the first embodiment.

FIG. 2

FIG. 2 is a perspective view showing the positional relationship among the two wafer stages, the reticle stage, the projection optical system, and the alignment systems.

FIG. 3

FIG. 3 is a plan view showing the arrangement of the driving mechanism for the wafer stages.

FIG. 4

FIG. 4 is a diagram showing the AF/AL systems provided for the projection optical system and the alignment systems, respectively.

FIG. 5

FIG. 5 shows a schematic arrangement of the projection exposure apparatus showing the layout of the AF/AL system and the TTR alignment system.

FIG. 6

FIG. 6 is a diagram showing the shape of the pattern formation plate shown in FIG. 5.

FIG. 7

FIG. 7 is a plan view showing the state in which the wafer exchange/alignment sequence and the exposure sequence are executed by using the two wafer stages.

FIG. 8

FIG. 8 is a diagram showing the state obtained after the change between the wafer exchange/alignment sequence and the exposure sequence shown in FIG. 7.

FIG. 9

FIG. 9 is a diagram for describing the operation for detecting the reference mark on the fiducial mark plate based on the use of the alignment system, in which FIG. 9(A) shows a state in which the reference mark MK2 on the fiducial mark plate

FM1 is positioned just under the alignment system 24a; FIG. 9(B) shows an example of the shape of the reference mark MK2 and a state of image pick-up for detecting the same by using the sensor of the FIA system of the alignment system 24a; and FIG. 9(C) shows a waveform signal obtained by the image processing system when the image of the mark MK2 is picked up by the sensor of the FIA system.

FIG. 10

FIG. 10 is a diagram for describing the operation for measuring the mark on the fiducial mark plate by using the reticle alignment microscope, in which FIG. 10(A) shows a state in which the reticle alignment microscope is used with the exposure light beam to detect the relative positions of the marks MK1 and MK3 on the fiducial mark plate FM1 and the projected images on the wafer surface, of the marks RMK1 and RMK3 on the reticle corresponding thereto; FIG. 10(B) shows the projected image on the wafer, of the mark RMK on the reticle R; FIG. 10(C) shows the mark MK on the fiducial mark plate; FIG. 10(D) shows a state of image pick-up performed in the system shown in FIG. 10(A), and FIG. 10(E) shows the waveform signal obtained by processing the picked up image.

FIG. 11

FIG. 11 is a conceptual diagram showing a state in which each shot on the wafer is subjected to exposure in accordance with the relative positional relationship between each shot and the exposure position finally calculated.

FIG. 12

FIG. 12 is a diagram showing the reticle stage for the double exposure, for holding the two reticles.

FIG. 13

FIG. 13 is a diagram for describing the order of exposure during the double exposure, in which FIG. 13(A) shows the state in which the wafer is exposed by using the reticle having the pattern A shown in FIG. 12, and FIG. 13(B) shows the state in which the wafer is exposed by using the reticle having the pattern B shown in FIG. 12.

FIG. 14

FIG. 14 is a diagram showing the order of exposure for each of the respective shot areas on the wafer held on one of the two wafer stages.

FIG. 15

FIG. 15 is a diagram showing the order of mark detection for each of the shot areas on the wafer held on the other of the two wafer stages.

FIG. 16

FIG. 16 is a diagram for describing the operation of the second embodiment, showing a state in which the interferometer having the length-measuring axis BI3Y is reset after completion of the alignment for the wafer W1 on the wafer stage WS1.

FIG. 17

FIG. 17 is a diagram for describing the operation of the second embodiment, showing a state in which the wafer stage WS1 is moved to the loading position, and the operation of the exposure sequence is performed on the side of the wafer stage WS2.

Description of Symbols

10: Projection Exposure Apparatus

24a, 24b: Alignment System

90: Main Control Unit

142, 144: Reticle Alignment Microscope

180: Center-Up

182: First Loading Guide

184: First Unload Arm

186: First Slider

188: First Load Arm

190: Second Slider

192: Second Loading Guide

194: Second Unload Arm

196: Third Slider

198: Second Load Arm

200: Fourth Slider

W1, W2: Wafer

WS1, WS2: Wafer Stage

PL: Projection Optical System

BI1X~BI5Y: Length-Measuring Axis

R: Reticle

MK1, MK2, MK3: Reference Mark

FIG. 1

90: Main Control Unit

From 70

From 38

From 38

To 80

To 38

To 38

FIG. 5

90: Main Control Unit

To 38